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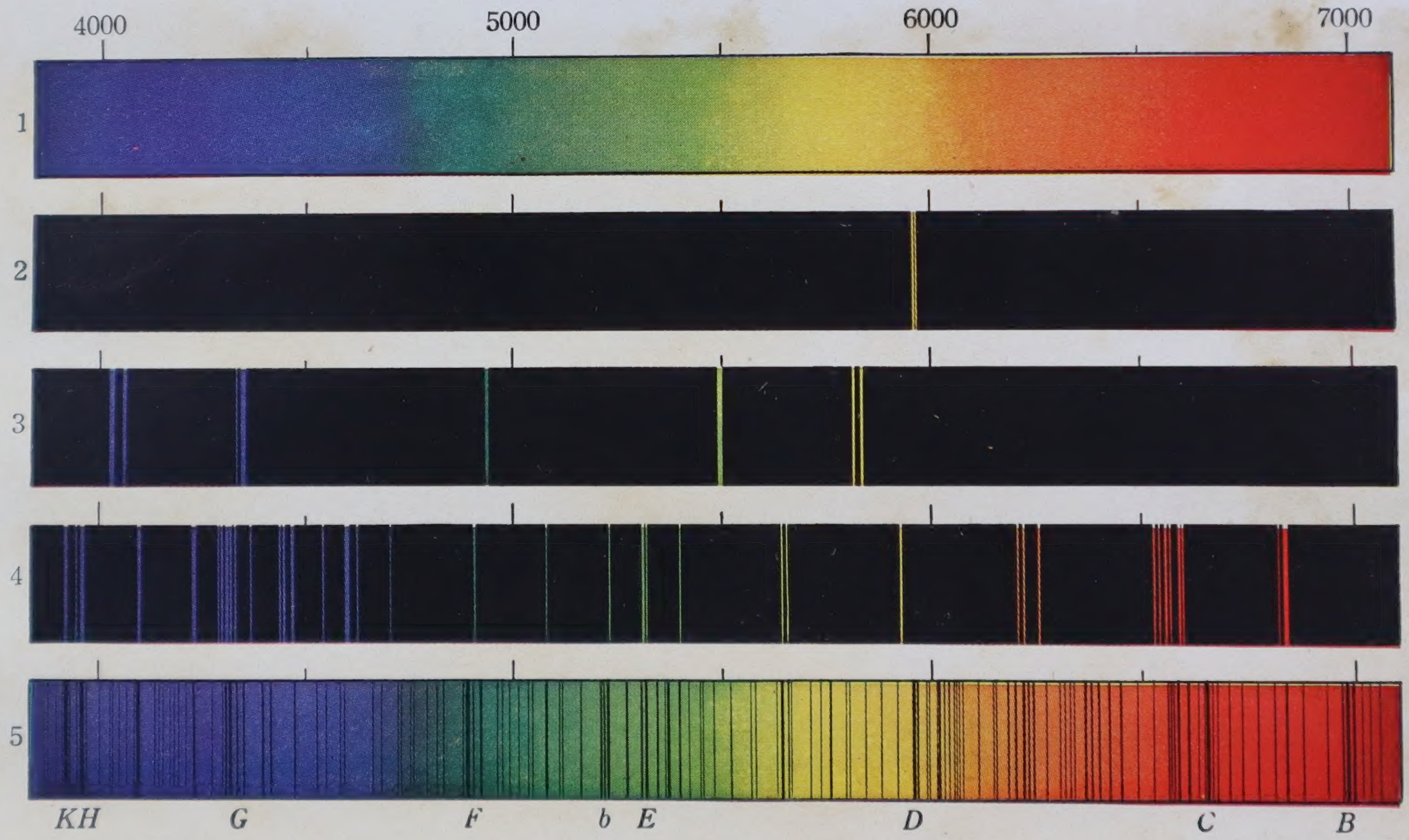
TLM



DIFFERENT TYPES OF SPECTRA

1, continuous spectrum from an incandescent solid; *2*, bright-line spectrum of sodium; *3*, bright-line spectrum of mercury; *4*, bright-line spectrum of calcium; *5*, absorption spectrum of the sun, showing some of the strongest Fraunhofer lines. Note the coincidence of the bright lines for sodium in *2* and the dark lines *D* in *5*

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CHEMICAL SPECTROSCOPY

BY

WALLACE R. BRODE

Professor of Chemistry in the Ohic State University

SECOND EDITION

FOURTH PRINTING

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PREFACE

The first edition of this book was a development from lecture notes and experiments used in a course in chemical spectroscopy which was started over ten years ago at the Ohio State University. The continued annual enrollment in this course of thirty to fifty students over this period has justified the feeling that there was a place in the university curriculum for such a course. Similar courses have been developed at many other schools. Courses in chemical spectroscopy are generally planned for the advanced undergraduate, with a usual prerequisite of general and analytical chemistry. It is not expected that all those who take this spectroscopy course will emerge as trained spectrographers but rather that the chemist, metallurgist, bacteriologist, or other student will learn from it to appreciate the spectrographic methods, to be able to interpret published results, and to apply spectrographic procedures to his problems.

The adoption of spectrographic methods of analysis as standard procedures in such important fields as the aluminum, steel, and magnesium industries and the development of equipment and methods to facilitate such, have led to an increased demand for trained spectroscopists.

The practical applications of spectroscopy have been elaborated on at the many Spectroscopic Conferences which have been held in recent years. Pioneering in this has been Dean George R. Harrison of Massachusetts Institute of Technology, who for ten years has been host through his Institute to the Summer Conference in Spectroscopy. Other conferences have included the Midwest Spectroscopic Conference, the meetings of the Committee on Spectroscopic Analysis (E-2) of the American Society for Testing Materials, the conferences on spectroscopy at the University of Chicago and the New York Academy of Science, and many symposia held at national and local meetings of the leading scientific societies.

Certain sections of this book, especially those dealing with apparatus and methods, have been prepared as a part of the author's contribution to the work of the American Society for Testing Materials Committee on Spectrographic Analysis, of which the author was chairman of the Subcommittee on Apparatus and Equipment.

The author has been chairman of a committee of the Chemistry and Chemical Technology Division of the National Research Council on the Application of Spectroscopic Methods to Chemistry, and it is hoped that as a part of that committee's work some system of uniform recording and cataloging of absorption spectra data may eventually be evolved. The methods of recording absorption spectra data in this book are subject to revision and should not be considered as the approved systems of this committee.

ACKNOWLEDGMENTS

The author acknowledges help and guidance from certain of the standard reference books in this field, including the works of W. Gerlach, G. Scheibe, F. Weigert, F. Twyman, A. C. Candler, H. E. White, E. S. Miller, H. Ley, D. M. Smith, and others, the tabular compilations of spectroscopic data such as the Harrison-M.I.T. tables, Kayser-Konen, Kayser-Ritchel, the International Critical Tables, Landolt-Bornstein, and the *Tables annuelles des constantes et données numériques*, as well as from the authors of many articles and editors of journals for data used in the preparation of curves and tables for illustrative or reference purposes.

The author wishes to acknowledge grants in aid for research which have been made to him by the National Research Council, the American Philosophical Society, the Society of Sigma Xi, the Eli Lilly Company, and others.

Acknowledgment of aid should be made to the John Simon Guggenheim Memorial Foundation for the grant of a fellowship for study on spectroscopic methods with Professor Arthur Hantzch of the University of Leipzig, Professor Victor Henri of the University of Zurich, and Professor E. C. C. Baly and Dr. R. A. Morton of the University of Liverpool, England.

For advice in the preparation of certain portions of this book and for illustrative materials the author is pleased to acknowledge assistance from Professors H. P. Knauss, H. L. Johnston, L. L. Quill, F. A. Jenkins, R. B. Brode, C. E. Boord, G. R. Harrison, W. F. Meggers, W. C. Fernelius, and D. H. Menzel; and to the Bausch and Lomb Optical Company, Eastman Kodak Company, Agfa Ansco Corporation, Adam Hilger, Ltd., Gaertner Scientific Company, Central Scientific Company, General Electric Company, Kipp and Zonen, Westinghouse, Hanovia, National Testing Laboratories, Applied Research Laboratories-Dietert, and other individuals and concerns as indicated in the text.

Acknowledgment is due Professor George H. Shortley for assistance in the revision of the discussion on the theory of spectra. The author also acknowledges, with thanks, permission to use the color plate

appearing as the frontispiece of this book. It is reprinted from S. R. Williams' "Foundations of College Physics," published by Ginn and Company. The author wishes to express his appreciation for permission from Dean George R. Harrison for use of data from his Wavelength Tables (M.I.T., 100,000 Spectrum Line Tables, John Wiley & Sons).

The author finds it a pleasant duty to acknowledge the cooperation of his wife, Ione Sundstrom Brode, and of Mrs. Julia Appleton Metcalf, who have assisted in the preparation of the manuscript and figures and in the proofreading of this material, also to Mrs. Metcalf and Miss B. J. Sipher for assistance in the preparation of the iron spectrum plates, and to Dr. Edwin Hodge for assistance in the preparation of certain figures.

WALLACE R. BRODE

OHIO STATE UNIVERSITY
March, 1943

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CHAPTER I

INTRODUCTION

In order that this book might serve the dual purpose of supplying spectroscopic information to chemical workers and of serving as a textbook for a course in chemical spectroscopy, it has been necessary to arrange the material on emission and absorption analysis in different parts. In view of the wide divergence in interests and fields of persons using spectroscopic information, certain portions of the text have been separated so that it is possible for those with limited fields of interest to cover only those sections which concern their work. The following subdivisions of the book are suggested for certain fields of interest.

Qualitative and quantitative analysis of elements: Chapters I, III, IV, V, XII, XIII, and XIV for metallurgists, inorganic chemists, analysts, and those interested in atomic identification and estimation.

Absorption spectra of organic and inorganic compounds: Chapters I, III, VI, VII, VIII, and XII for organic chemists, biochemists, medical research workers, and those concerned with special inorganic applications or dye chemistry.

A set of experiments on the application of spectrographic methods (Chapter XII) follows the theoretical discussion. A number of tables and charts for the solution of these experiments and for general use in the interpretation and application of spectroscopic methods have been included.

Theory of Light

The accepted theory of the nature of light is a combination of many earlier theories, including Newton's corpuscular theory (1666), the wave theory of Huygens (1673), the electromagnetic theory of Maxwell (1860), and the more recent work of Hertz, Lorentz, and Planck. The fusion of these theories provides for a corpuscular form of energy (quantum) propagated in a wave form (*A23, A104*). From the simple theory of wave motion we can indicate the essential characteristics of light. In Fig. 1.1 the distance from *A* to *B*, representing the length of a complete wave or cycle, is known as the wavelength. The number of these complete cycles or waves in a unit length (*C* to *D*) will be known as the wavenumber.

If Y is a fixed point in space, past which the wave front is moving, then the number of complete cycles or waves passing this point in a given time will be known as the frequency of the light.

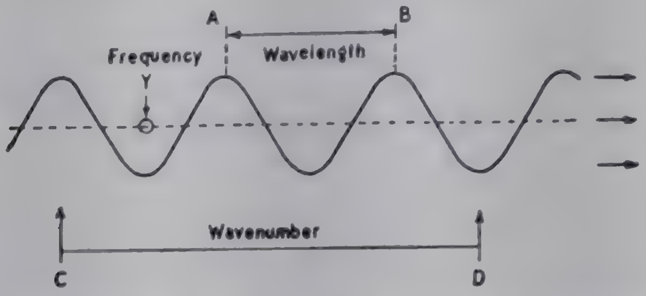


FIG. 1.1. Graphical indication of the relation between wavelength (λ), wavenumber (ν'), and frequency (ν).

Wavelength (λ) = distance between A and B.
Wavenumber (ν') = number of waves in unit length (C–D).
Frequency (ν) = number of waves passing a fixed point (Y) in a unit time.

By consulting Fig. 1.2 some conception can be formed of the dimensions of the light wave and its relation to the other vibrating forms of energy propagation. In this figure the space between A and B represents the photographic range, i.e., the spectral region over which the photographic plate will give a direct response to light rays (not including x-rays). The narrower dark band between A and B represents the portion of the photographic spectrum which produces the sensation of visible light.

In the indication of the relation between wavelength, wavenumber, and frequency, we may use the following notations:

$$\frac{1}{\text{WAVELENGTH}} = \text{WAVENUMBER} = \frac{\text{FREQUENCY}}{\text{SPEED OF LIGHT}}$$

Using tne terms λ for wavelength, ν' for wavenumber, ν for frequency, and c for the speed of light we obtain the expression

$$\frac{1}{\lambda} = \nu' = \frac{\nu}{c}$$

The speed of light has been shown to be constant over the spectral range with which we are concerned, and in meters is expressed as 2.99796×10^8 meter (or 10^{10} cm) per sec, in vacuum. For accurate physical work it is quite essential to correct light measurements for the variation in the density of the medium through which the light passes, or in which it is measured. For most of the necessary chemical measurements, especially those dealing with absorption spectra and qualitative and quantitative emission analysis, we can deal with tables prepared from data observed in air at standard conditions, or even ignore the necessary correction where the probable error of the work exceeds this correction. In general, we express c as 3×10^{10} cm per sec rather than as 2.99796×10^{10}.

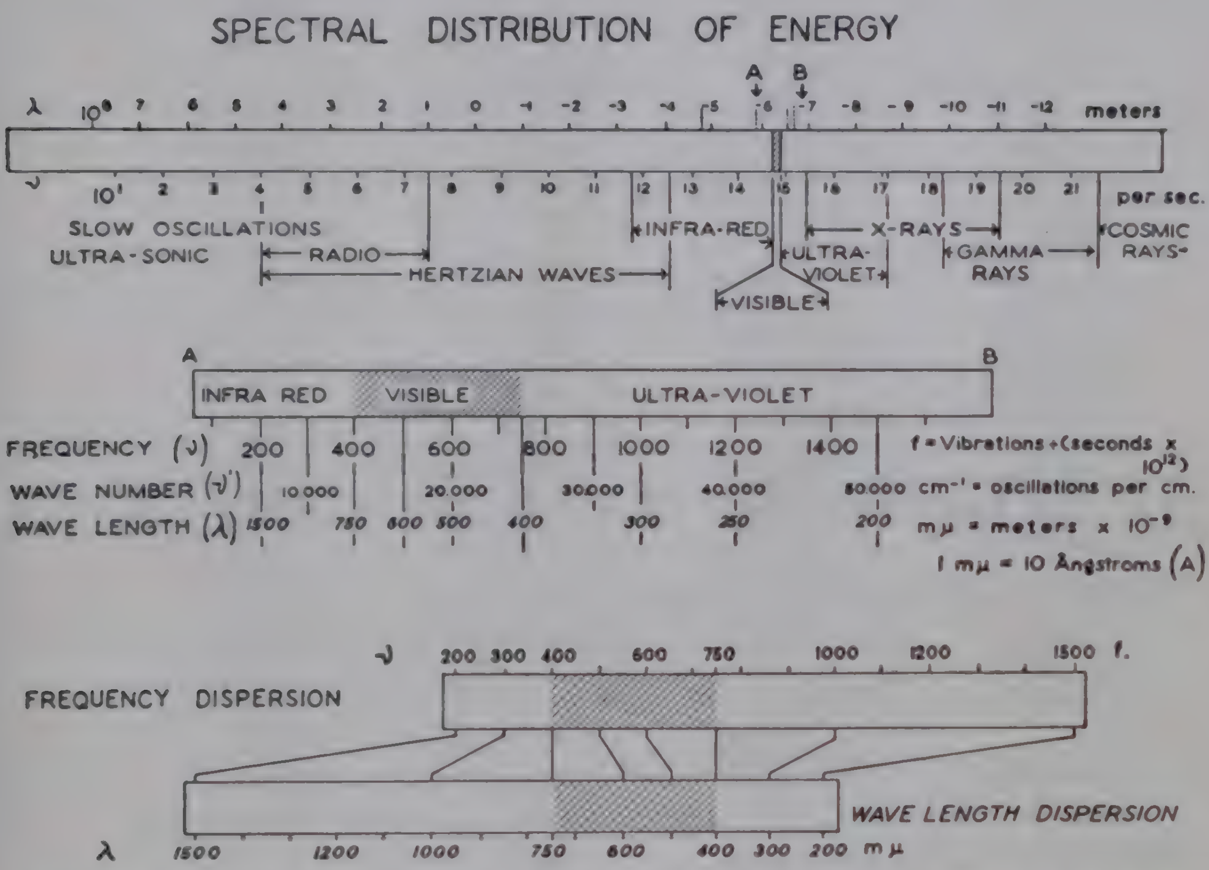

SPECTRAL DISTRIBUTION OF ENERGY
A
B
λ
10⁸ 7 6 5 4 3 2 1 0 -1 -2 -3 -4 -5 -6 -7 -8 -9 -10 -11 -12 meters
ν
10¹ 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 per sec.
SLOW OSCILLATIONS
ULTRA-SONIC
RADIO
HERTZIAN WAVES
INFRA-RED
VISIBLE
ULTRA-VIOLET
X-RAYS
GAMMA RAYS
COSMIC RAYS
A
B
INFRA RED
VISIBLE
ULTRA-VIOLET
FREQUENCY (ν) 200 400 600 800 1000 1200 1400
f = Vibrations ÷ (seconds x 10¹²)
WAVE NUMBER (ν′) 10.000 20.000 30.000 40.000 50.000 cm⁻¹ = oscillations per cm.
WAVE LENGTH (λ) 1500 750 600 500 400 300 250 200
mμ = meters x 10⁻⁹
1 mμ = 10 Ångstroms (A)
FREQUENCY DISPERSION
ν 200 300 400 600 750 1000 1200 1500 f.
WAVE LENGTH DISPERSION
λ 1500 1200 1000 750 600 400 300 200 mμ

FIG. 1.2. Spectral distribution of radiant energy. In the lower portion of this figure are shown the region from A to B on a linear scale in frequency (above) and a linear scale in wavelength (below).

The limits in wavelength of the visible spectrum are found by observation to be between 4×10^{-7} and 7.5×10^{-7} meter. The accuracy with which the earlier workers could determine wavelength values within this region (see Chapter IV) justified the use of a number with four significant figures in front of the decimal point, so that the limits of the visible spectrum might thus be indicated as from 4000×10^{-10} to 7500×10^{-10} meter. The unit of measurement in this system was called an angstrom after the Swedish physicist, Ångström, and is now defined as 1/6438.4696 of the wavelength of the cadmium red line, rather than one ten thousand millionth (1/10,000,000,000) of a meter. The increase in accuracy of modern physical methods has enabled us to measure wavelength values to an accuracy of one part in about ten million, or to about four significant figures after the decimal point in the angstrom system of notation.

In many of the data published on the absorption spectra of organic compounds and visible color, the accuracy of the work does not justify the use of more than three significant figures, and in the infrared the wavelength values increase to such a size that the use of the angstrom unit would become awkward. Hence, a variety of wavelength terms are used depending upon the spectral region and character of the data considered. For reasons which will be discussed later (Chapters II and IX), the use of frequency or wavenumber values rather than wavelength is

---

TABLE 1.1

DEFINITION OF IMPORTANT UNITS

Light

Wavelength, λ

Angstrom, A = 1/6438.4696 of the wavelength of the Cd red line
Among other symbols that have been used for this term are IA, Å, and AU. = meters $\times 10^{-10}$
Millimicron, mμ = meters $\times 10^{-9}$
Micron, μ = meters $\times 10^{-6}$

Wavenumber, ν'

Waves per centimeter = cm^{-1}

Frequency, ν

Fresnel, f = vibrations per (second $\times 10^{-12}$)

Interrelation between above units

$1/\lambda = \nu' = \nu/c$ $\quad c$ = speed of light = 3×10^{10} cm per sec

Example of interconversion

$1/\lambda$ in m$\mu \times 10^7 = \nu'$ in cm^{-1}; ν' in $\text{cm}^{-1} \times 3 \times 10^{-2} = \nu$ in f
e.g., 400 mμ = $1/400 \times 10^7$ = 25,000 cm^{-1}; 25,000 cm^{-1} = $3 \times 10^{-2} \times 25{,}000$ = 750 f

Absorption

I_0 = incident intensity
I = transmitted intensity
I/I_0 = transmission or transmission factor (T)
$1 - T = A$ = absorption

$T \times 100$ = per cent transmitted or transmittancy (t)

$I = I_0 \cdot 10^{-kcd}$, where c = concentration in grams per liter, d = thickness in centimeters, and k = specific extinction.
E = *extinction* = Log $I_0/I = kcd$
k = *specific extinction* = E/cd
Log E = *log extinction*
ϵ = molecular extinction = $k \times$ molecular weight

Extinction values (E, k, *and* ϵ) are often recorded as exponential or power values, especially where the units become large or difficult to present graphically. For example: $k \times 10^3$, log E, $\epsilon \times 10^5$, log ϵ, etc.

---

found to be more convenient with certain forms of data. This is especially true in the assignment of energy levels in atomic spectra, and the determination of series relationships in absorption spectra (*A21*, *A99*, *B21*, *B29*).

Recommended System of Recording Absorption Spectra Curves

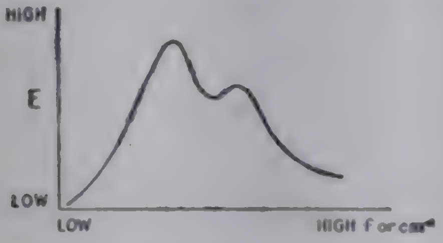


FIG. 1.3*a*. Recommended method of plotting extinction against frequency (f) or wavenumber (cm^{-1}).

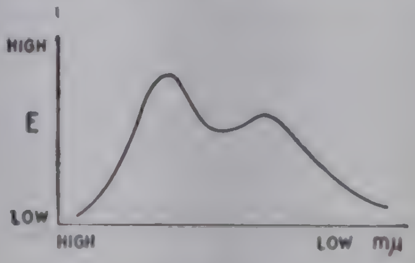


FIG. 1.3*b*. Recommended method of plotting extinction against wavelength (mμ).

Use only k, E, ϵ, $\log E$, $\log \epsilon$, or powers of $10 \times k$, E, or ϵ as ordinate, and plot with increasing values upwards.

Use f (fresnel) for frequency, and plot with increasing values to the right, i.e., ultraviolet on the right and infrared on the left.

Use cm^{-1} or (cm$^{-1} \times 10^{-3}$) for wavenumber, and plot with increasing values to the right.

Use mμ for wavelength, and plot with increasing values to the left, i.e., ultraviolet on the right and infrared on the left.

While the calibration of the apparatus or the use to which the data is to be put may determine or influence the system of recording, it is suggested that, as far as possible, published data conform to the above suggestions. An emphasis on the presentation of data on a wavenumber or frequency scale seems desirable in view of the advantages that these dispersion scales give in a study of component and harmonic structure.

The reader may note that the author has not been consistent, either in this book or his published articles, in the system of notation which he has used. In many of the published articles the author has conformed to the systems used in the laboratories in which the measurements were made. So far as this book is concerned, an attempt has been made to acquaint the reader with the various systems in use, and, in some cases, to compare their application in the presentation of the same or similar data.

Positive and Negative Spectrograms

There is no common agreement among spectroscopists as to the proper method for the presentation of spectrum photographs or the reproduction of spectrograms in published data. A spectroscopist should be adept at mental inversion of black and white so as to compare positive and negative spectrograms. A *positive spectrogram*, **P**, is defined as a spectrogram in which the lines or bands appear as white, with a black background representing those portions of the spectrogram in which there is no radiant energy. A *negative spectrogram*, **N**, is defined as a spectrogram in which the lines or bands appear as black, with a clear or white background representing those portions of the spectrogram in which there is no radiant energy. The negative spectrogram is similar to the photographic negative obtained with a spectrograph; the positive appears as the contact print of such a negative. Since there may be some confusion as to whether a positive or negative spectrogram is reproduced the symbols **P** and **N** have been inserted in the titles to figures to indicate the corresponding positive and negative character of the spectrogram. See Chapter XIII for special methods of producing positive and negative spectrograms.

LITERATURE

Note: A list of books and articles in the fields of *general spectroscopy* (*A*), *absorption spectra* (*B*), and *research publications* (*C*) is to be found in the Bibliography (pages 383 to 397). Reference to books and articles in this list are made by letter and number, e.g., *A26*, *C17*, etc.

General

S. JUDD LEWIS, "Spectroscopy in Science and Industry" (*A63*).
W. E. FORSYTHE and others, "Measurement of Radiant Energy" (*A23*).
D. M. SMITH, "Metallurgical Analysis by the Spectrograph" (*A85*).
F. TWYMAN, "The Spectrochemical Analysis of Metals and Alloys" (*A104*).
T. R. P. GIBB, "Optical Methods of Chemical Analysis" (*A30a*).

Reference

BRAGG (*A7*), FABRY (*A21*), GIBSON (*B21*), WEIGERT (*A99*), MELLON (*C140*).

CHAPTER II

ATOMIC AND MOLECULAR SPECTRA

The discussion in this chapter is an elementary presentation of the theory of atomic and molecular spectra. Although some understanding is helpful, the complete comprehension of the theory of spectra, or even of the material in this chapter, is not essential to the use of spectroscopic methods in many chemical problems. In particular, workers in the fields of organic and biochemistry with problems dealing with absorption-spectra data may find little of advantage to them in this chapter.

In this review discussion no attempt has been made to give complete references, but a selected bibliography will be found at the end of the chapter to which the reader may refer for further information.

ORIGIN OF SPECTRA

Excited atoms are known to emit light of definite wavelength values, and the dispersion of this light by a spectroscope or spectrograph produces a spectrum which is characteristic of the atom or molecule. The means of excitation may be an arc, spark, flame, or discharge tube. The production of emitted light or radiant energy results from the falling of electrons into lower levels of the atom. These electrons have been pushed into outer levels by an excitation force. The energy (E) which is evolved may be represented as the difference in energy of the two electronic states, and may be indicated by the equation

$$E = E_2 - E_1 = h\nu$$

where E_1 represents the total energy of the atom in the lower electron state, and E_2 the total energy in the higher electron state. This difference may be equated to $h\nu$, where h is the Planck constant and ν the frequency of the light which is emitted. One may thus measure energy in terms of frequency of emitted light, just as one may also measure energy in calories or volts. Since each spectrum line is the result of energy lost by the excited atom, it follows that, if light is the exciting medium, absorption of light of the same wavelength may take place as a means of exciting an atom.

As has been demonstrated by theoretical and experimental work, this emission and absorption of energy takes place in accordance with fixed and well-defined rules. The electrons which have been forced away from the nucleus can be forced only to certain predetermined positions, and the return of the electrons to normal position can take place only through a certain number of finite moves; i.e., it may make the complete change in one move or it may return to an intermediate level and go from there to its stable or normal level.

Hydrogen Spectrum

The simplest atom is hydrogen, and it will serve as an excellent example of these effects. The hydrogen spectrum (Fig. 2.1) is composed of a number of lines which may be arranged in several series. From the Grotrian diagram (Fig. 2.2) it can be seen that these lines are related to a series of levels which may be represented as increasing voltage or frequency on the energy ordinate. It is to be noted that the greatest energy is required to move the electron from its stable position (lowest level) to the next higher level. As would be expected in the separation of two oppositely charged bodies, each unit increase of separation requires a smaller increase in energy until at last the electron is completely removed from the atom shell and ionization is said to have occurred.

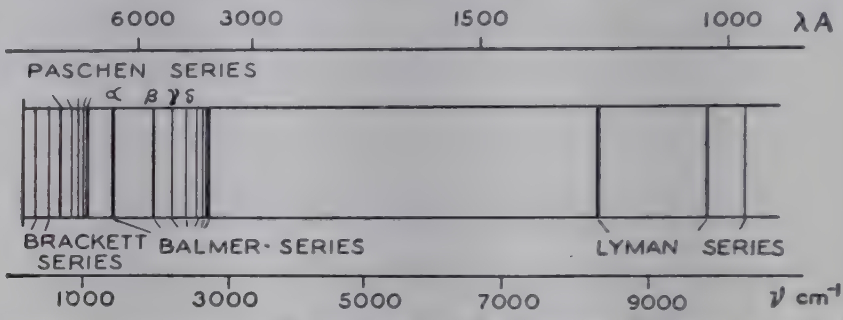


Fig. 2.1. Hydrogen spectrum. (See also the hydrogen Balmer series in the flash spectrogram, Fig. 4.1.)

The various spectral series which are to be found in the hydrogen spectrum may be classified in accordance with the electron level to which the electron returns or, in absorption, to the electron level from which the electron was dislodged. The Balmer series which includes the visible lines of the hydrogen spectrum thus represents the return of electrons from other, higher levels to the second level. It should be noted that an electron in a higher level may return to a lower level through several different paths, i.e., an electron in the fourth level may return to the third (Paschen series, line 18,751), thence to the second level (Balmer series, line 6562), and finally to the first level (Lyman series, line 1215). It may also go directly to the first level from the third level and avoid the second level (Lyman series, line 1025); or it may go directly to the second level from the fourth level and avoid the third level (Balmer series, line 4861). The number of atoms excited to the various levels is influenced by the exciting conditions, which result in markedly different spectra as observed in the arc and spark excitation of certain elements.

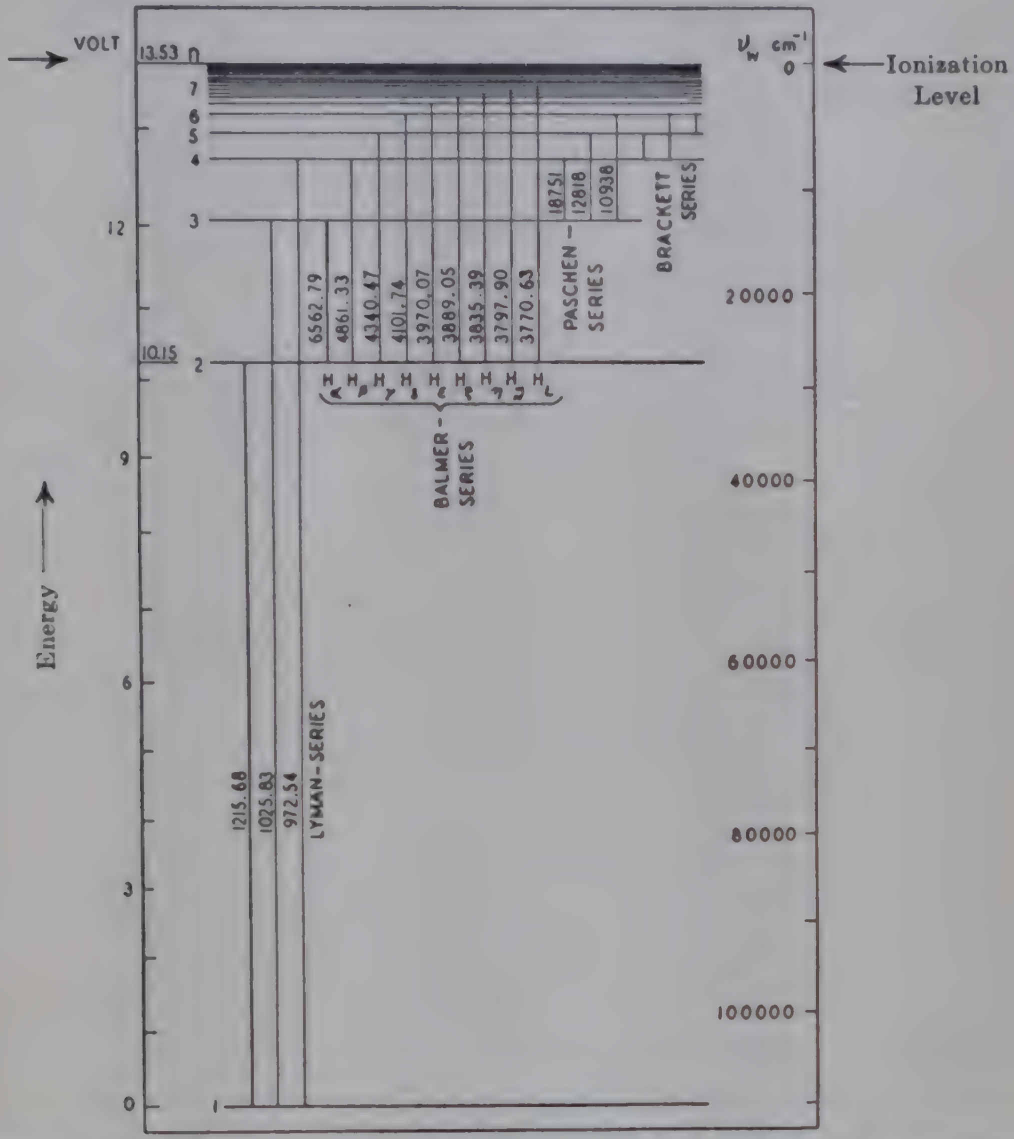


FIG. 2.2. Energy level diagram of hydrogen; vertical lines indicate electron transitions. The electron transition from a higher to a lower level causes an emission line of the wavelength indicated on each line; i.e., the transition of an electron from the third level to the second level results in the emission of energy in the form of light with a wavelength of 6562.79 A.

The top horizontal line in this diagram indicates the energy for complete ionizaton of the electron. The distances of levels below this ionization potential are expressed in cm⁻¹, which can be represented by the formula R/n^2. The difference between two levels on this cm⁻¹ scale will give the frequency in cm⁻¹ of the line produced by an electron transition from the higher to lower level.

These series of lines may be incorporated into an equation as first suggested by Balmer, in the form

$$\nu' = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

where ν' is the wavenumber of the emitted line R is a constant with the value 109,677.76 cm⁻¹, and n_1 and n_2 are the numbers of the final and initial electron states respectively. By the use of this formula the spectrum lines for the Balmer series (final term $n_1 = 2$, and variable terms $n_2 = 3, 4, 5, 6$, etc.) can be calculated as shown in Table 2.1.

TABLE 2.1

BALMER SERIES OF HYDROGEN LINES

n_2	ν' Calculated	λ Calculated	λ Observed
α 3	15,233.15 cm^{-1}	6564.62 A	6564.60
β 4	20,564.76	4862.68	4862.68
γ 5	23,032.53	4341.68	4341.68
δ 6	24,373.05	4102.89	4102.89
ϵ 7	25,181.34	3971.19	3971.19

Graphically one may represent this by plotting the term values from R/∞ (dissociating term) to $R/4$, against wavenumber, which will give a uniform slope for the points of intersection of the frequency values with the corresponding term values (Fig. 2.3).

SPECTRAL NOTATIONS

The spectra of elements involving only one electron such as hydrogen, ionized helium, and the second ionized spectra of lithium are expected to be of the same type. This expectation has been confirmed by experimentation. With more complicated atoms the possible series overlap to a much greater extent since the removal of one electron does not so greatly alter the remaining negative charge or electron content, and hence the energy values are of a lower order of magnitude.

The various series of lines in the spectra of elements with more than one electron are often distinguished by their appearance, and hence the designations of sharp, principal, diffuse, and fundamental (Bergman) have been used. The identification of series may be made in accordance with certain properties. For example, the lines of the principal series will be apparent in the absorption spectrum produced by the element in a vapor state and are usually subject to reversal, i.e., self-absorption due to absorption of the light by cooler vapors surrounding the hot spark or arc. Other properties which may be used to clarify the assignment of the series and terms include such effects as the Zeeman effect, excitation potential, Stark effect, and Paschen-Bach effect.

Rydberg has developed a general formula for these series which may be expressed as $\nu = \nu_1 - R/(m + a)^2$, where a is a constant characteristic of the series, and m is a series of integral series values. R, known as Rydberg's constant, is constant for practically all series, and ν is the frequency of the limit of the series. It is thus possible to indicate each series' value by a definite quantum formula although for each series and element the value a will be different. A less precise, but more generally applicable, method is to indicate the changes in levels or terms by a code system of notation or classification. In applying this system of classification (*A75*) developed by Paschen and Götze to a typical element such as sodium, the lowest terms of the four series corresponding to the sharp, principal, diffuse, and fundamental are indicated by the terms $3S$, $3P$, $3D$, $4F$, respectively. The higher terms in each of these series will then be indicated by mS, mP, mD, mF, where m is an integer and equal to or greater than the numerical prefix of the term to which the electron falls. With an increase in the number of electrons in the atom there will be

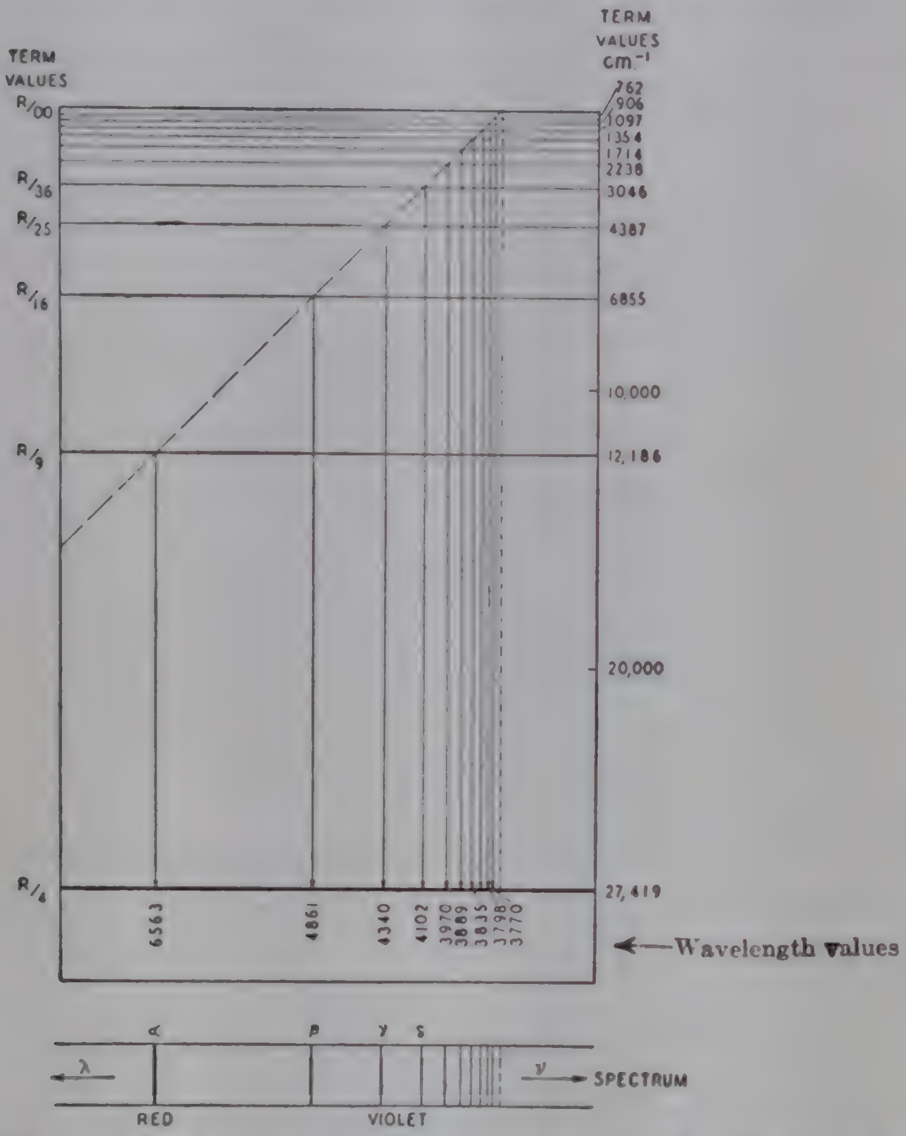


FIG. 2.3. Level diagram of the Balmer series. The lower projected spectrum is on a uniform frequency scale. After Candler (*A9*).

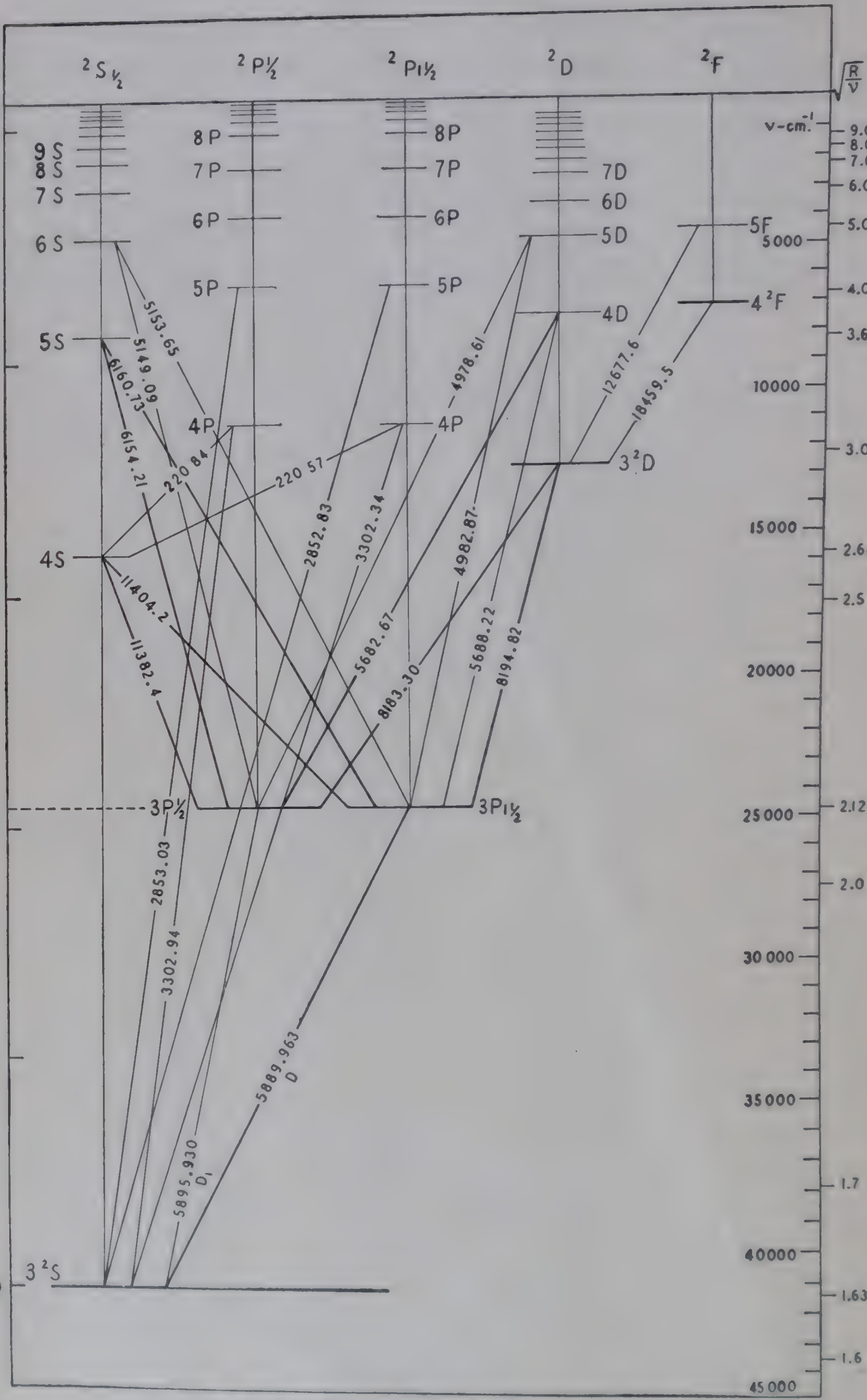


FIG. 2.4. Level diagram of sodium.
After Grotrian, *Graphische Darstellung der Spektren* (A33). See Table 2.4.

additional series which are indicated by such terms as G, H, etc. It should be noted that, in the development of the term notation used in spectral interpretation, the earlier presentations assigned the lowest level as equal to $1S$, whereas in the present accepted notation the normal or ground level has been given the quantum number representative of the electron shell.

In accordance with this system of notation the spectrum line series of sodium may be indicated as

Principal series	$3S - mP$	$m = 3, 4, 5 \cdots$
Sharp series	$3P - mS$	$m = 4, 5, 6 \cdots$
Diffuse series	$3P - mD$	$m = 3, 4, 5 \cdots$
Fundamental series	$3D - mF$	$m = 4, 5, 6 \cdots$

In Fig. 2.4 the first line of the principal series of sodium may be indicated as $3S$–$3P$, which involves an electron change from the $3P$ level to the $3S$ level. As will be noted in Fig. 2.4, there are certain limitations of combinations, such as the combination of terms with only those series on either side, i.e., an S term combines only with a P term, P terms combine only with S or D, and D terms only with P and F terms.

Spectral terms may be of a simple singlet type or more complex doublet, triplet, or higher multiplet types. To designate this, one states the multiplicity by means of a superscript prefix, 2, 3 etc. (as ^2P, ^3P, etc.), to the term values to indicate this doublet, triplet, or higher system. A subscript suffix of 0, 0½, 1, 1½, 2, 2½, etc. (as P_0, $P_{0\frac{1}{2}}$, etc.), is added to indicate levels (J values). Alternate groups in the periodic table exhibit odd and even multiplicities, the elements with odd valences having even multiplicities in accordance with the number of available electrons. For example, potassium has only a doublet system; calcium, a singlet and triplet; scandium, doublet and quartet; titanium, singlet, triplet, and quintet, etc. In Fig. 2.5, $3^2S_{0\frac{1}{2}} - m^2P_{0\frac{1}{2}}$ indicates the lower-frequency, and $3^2S_{0\frac{1}{2}} - m^2P_{1\frac{1}{2}}$ the higher-frequency lines of the principal series of doublets of which the yellow D lines are the first members. In the sharp and fundamental series this separation between doublets is constant on a frequency scale, and the separation of the doublets in the principal and diffuse series is associated with the separations of the sharp and fundamental series although the separation is not constant.

Fowler (*A24*) summarizes the definition of these series for doublet spectra, as in the alkalies, as follows:

1. The sharp series exhibits a constant difference in wavenumber in the doublet types with the higher-frequency line showing a weaker intensity. Since a constant difference is shown between doublet pairs,

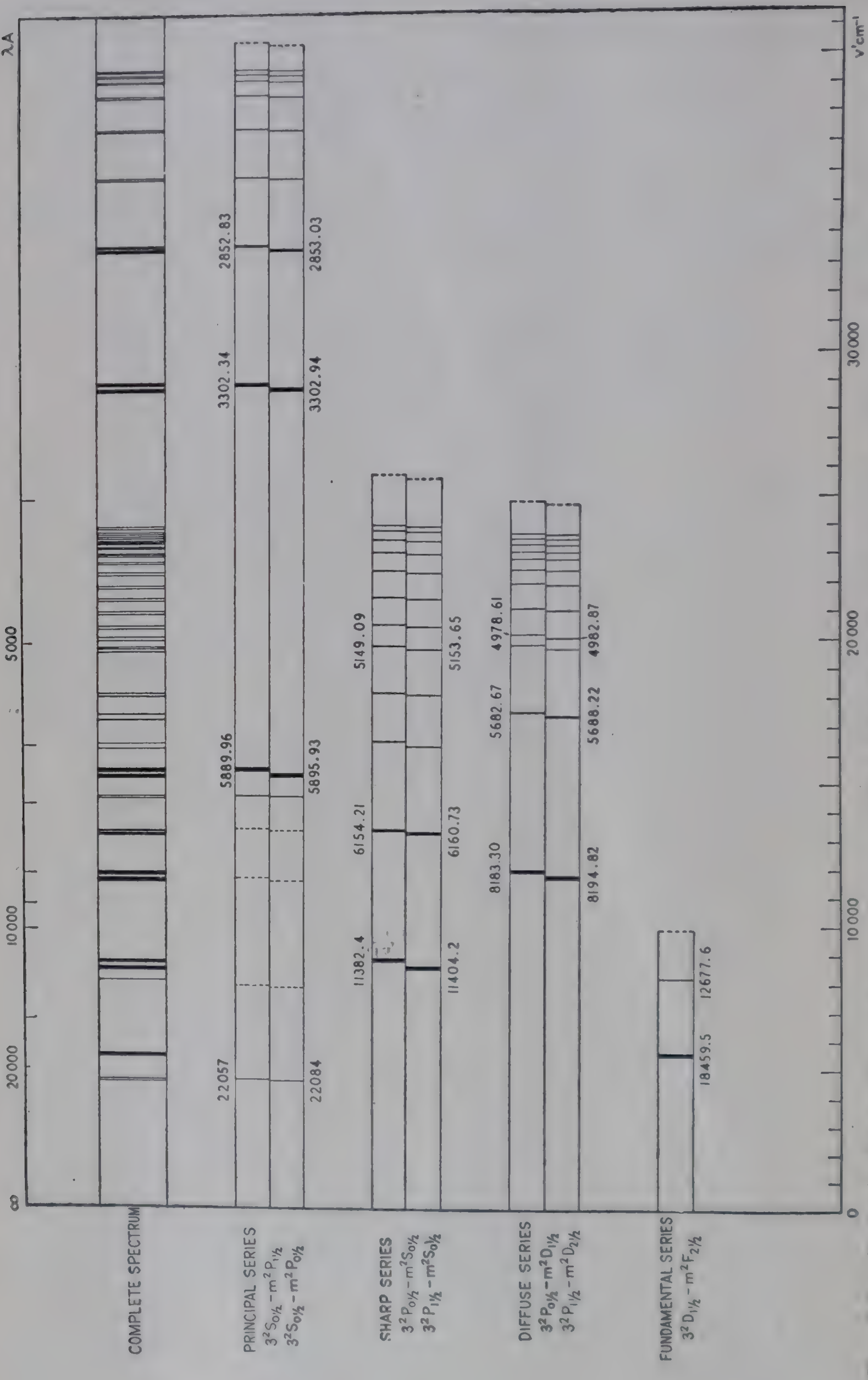


FIG. 2.5. Series in the sodium spectrum (on a uniform frequency scale) and the combination of these series to form the completed spectrum.

the limiting frequency of these doublet series will be different by this amount, but the value, a, of Rydberg's formula will be constant.

2. The principal series exhibits a reverse in the intensity ratio as compared with the sharp series, in that the higher-frequency component has the greater intensity. In the first members the difference in the doublet pair is the same as in the sharp series, but the higher members show decreasing differences so that the limiting frequency values of both series of doublet lines are the same. This involves in the Rydberg formula a constant, ν_1, and a variable, a.

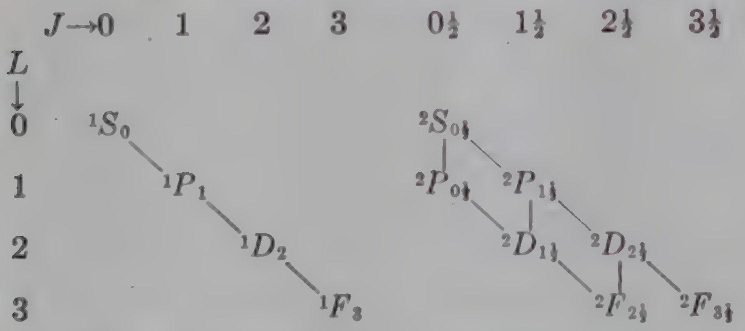
3. The diffuse series is somewhat complex, involving lines showing the separations of the sharp and fundamental series. The three lines may be considered as two pairs having one line in common (that of the higher-wavenumber component). The middle component is the strongest and is separated from the low-wavenumber component, which is the weakest in intensity, by the frequency difference of the fundamental series. The lines may be indicated as α, β, and γ, α being the component of highest frequency. The β line approaches the γ line at the series limit so that but two lines appear at the limit. Furthermore, the limits of the diffuse series are the same as those of the sharp series.

4. The fundamental series in a doublet spectrum involves pairs of lines with a constant separation equal to the β-γ interval in the first of the diffuse series group of lines.

5. Additional series are possible, of course, but little is known of their characteristics. They originate from terms indicated as G, H, etc.

TABLE 2.2

Levels of Singlet and Doublet Terms



Singlet Terms (*a*) Doublet Terms (*b*)

The explanation of the splitting of separate terms into levels of slightly different energy content is based on an angular momentum, which is expressed as J, where J may equal $0\frac{1}{2}$, $1\frac{1}{2}$, etc., in even multiplicities, or 0, 1, 2, etc., in odd multiplicities. In spectral theory, L is used to indicate the orbital angular momentum which can take on only integral values. Terms corresponding to $L = 0, 1, 2, \cdots$ are designated by S, P, D, F, etc. Total angular momentum (J) results from the combination of electron orbital momentum and spin angular momentum. Where there is but one electron outside the nucleus or core (as in sodium), the spin is 1/2, and J can have two values, $(L + \frac{1}{2})$ and $(L - \frac{1}{2})$; this being the origin of the doublet structure (Table 2.2[*b*]). In this table the lines indicate the observed transitions which are presented graphically in the Grotrian diagram of the sodium spectrum (Fig. 2.4). With regard to intensities of lines, Sommerfeld has shown that the strongest lines are produced when both L and J are changed in the same direction (*A87*).

Spectral Terms and the Periodic Table

The foregoing discussion has dealt with the atomic spectra of hydrogen and the alkali metals. The elements in any one group or subgroup in the periodic table exhibit similar spectra, and spectra increase in complexity in the higher groups in the periodic table (Table XII). In the second group in the periodic table (alkaline-earth metals), the spectra are characterized by the presence of singlet and triplet systems, involving as before the principal, sharp, diffuse, and fundamental series. The next periodic group (B, Al, etc.), the trivalent group with three electrons in the outer shell, gives spectra showing doublets and quartets. In the next, periodic column, singlets, triplets, and quintets occur, and thus the maximum values increase in succeeding columns in the periodic table until septets are produced. The J values for the total angular momentum for odd spectral series (singlets, triplets, quintets, etc.) will be found to be integer values, while in the even series (doublets, quartets, etc.) the electronic angular momentum values (J) will be found to be half-integers ($\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, $\cdots$).

The Bohr theory assigns to the atom a certain number of shells, and all the electrons in each shell have the same series quantum number, i.e., for the K shell the series quantum number, $n = 1$; for the L shell, $n = 2$; for the M shell, $n = 3$; etc. Each shell has been divided into subshells in accordance with the number of s, p, d, and f electrons present. Orbital quantum numbers, l, have been assigned to each of these subshells as indicated in Table 2.3.

It is thus possible to classify the elements of the periodic table in accordance with their electron configuration and predict the character of the spectra and the normal states of each atom. For example, hydrogen has one electron of the 1s state, and in accordance with the rules which have been discussed it will have a normal state of $^2S_{0\frac{1}{2}}$ (odd numbers of electrons will have half-integral J values, and the multiplicity will be

TABLE 2.3

Assignment of Electrons in Shells

Shell	*K*	*L*		*M*			*N*				*O*, *P*, etc.
Total quantum number (n)	1	2		3			4				
Subshell	1*s*	2*s*	2*p*	3*s*	3*p*	3*d*	4*s*	4*p*	4*d*	4*f*	
Azimuthal quantum number (l)	0	0	1	0	1	2	0	1	2	3	
Number of electrons	2	2	6	2	6	10	2	6	10	14	

doublet for Group I of the periodic table). Helium, on the other hand, has two *s* electrons in the $n = 1$ shell which are indicated as $1s^2$, and a normal state, $^1S_0$.

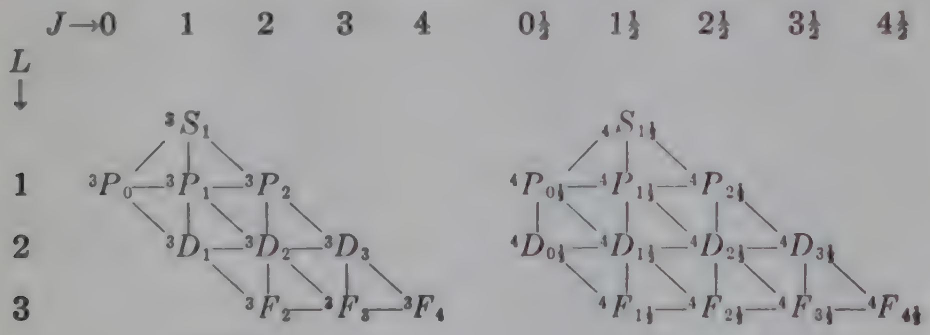
The second period of the periodic table involves the *L* shell. For all these members the *K* shell is complete and hence all atoms will have a common part in their configuration of $1s^2$. The electron configurations of some of the elements are indicated in Table 2.5; for example, the electron configuration of carbon may be expressed as $1s^2\,2s^2\,2p^2$, and the ground or normal state is $^3P_0$.

The higher multiplicity tables (quintets, sextets, septets, and octets) follow the same general rules as the four multiplicity tables shown in Tables 2.2 and 2.4.

TABLE 2.4

Levels of Triplet and Quartet Terms

The singlet, triplet, or quartet levels occurring in any one horizontal line together constitute a term.


$J \rightarrow 0$ 1 2 3 4
$0\frac{1}{2}$ $1\frac{1}{2}$ $2\frac{1}{2}$ $3\frac{1}{2}$ $4\frac{1}{2}$
$L \downarrow$
1
2
3
$^3S_1$
$^3P_0$ $^3P_1$ $^3P_2$
$^3D_1$ $^3D_2$ $^3D_3$
$^3F_2$ $^3F_3$ $^3F_4$
$^4S_{1\frac{1}{2}}$
$^4P_{0\frac{1}{2}}$ $^4P_{1\frac{1}{2}}$ $^4P_{2\frac{1}{2}}$
$^4D_{0\frac{1}{2}}$ $^4D_{1\frac{1}{2}}$ $^4D_{2\frac{1}{2}}$ $^4D_{3\frac{1}{2}}$
$^4F_{1\frac{1}{2}}$ $^4F_{2\frac{1}{2}}$ $^4F_{3\frac{1}{2}}$ $^4F_{4\frac{1}{2}}$

Triplets Quartets

S terms have only one level, whose *J* value is equal to one-half the multiplicity minus ½; i.e., for quartet *S* terms the *J* value will equal one-half of 4, or 2, less ½, or 1½. The total number of levels in a term of any of the other series, *P*, *D*, *F*, etc., will never be greater than the multiplicity; i.e., there are only two levels in *P*, *D*, and *F* doublets; in the quartets, there are three *P*, four *D*, and four *F* levels. There are never more than three *P* levels, five *D* levels, or seven *F* levels. The selection

TABLE 2.5

PARTIAL TABLE OF ELECTRON CONFIGURATION OF THE ELEMENTS

(For a complete table, see White, *(A103)* p. 82; Candler, *(A9)* p. 194; *(C136)*, etc.)

Atomic No.	Element	Shells								See Table I Page 400
		K $(n = 1)$ $l = 0$	*L* $(n = 2)$ $l = 0, 1$		*M* $(n = 3)$ $l = 0, 1, 2$			*N* $(n = 4)$ $l = 0, 1, 2, 3$		Normal State
1	H	$1s$								${}^2S_{0\frac{1}{2}}$
2	He	$1s^2$								${}^1S_0$
3	Li	$1s^2$	$2s$							${}^2S_{0\frac{1}{2}}$
4	Be	$1s^2$	$2s^2$							${}^1S_0$
5	B	$1s^2$	$2s^2$	$2p$						${}^2P_{0\frac{1}{2}}$
6	C	$1s^2$	$2s^2$	$2p^2$						${}^3P_0$
7	N	$1s^2$	$2s^2$	$2p^3$						${}^4S_{1\frac{1}{2}}$
8	O	$1s^2$	$2s^2$	$2p^4$						${}^3P_2$
9	F	$1s^2$	$2s^2$	$2p^5$						${}^2P_{1\frac{1}{2}}$
10	Ne	$1s^2$	$2s^2$	$2p^6$						${}^1S_0$
11	Na	$1s^2$	$2s^2$	$2p^6$	$3s$					${}^2S_{0\frac{1}{2}}$
12	Mg	$1s^2$	$2s^2$	$2p^6$	$3s^2$					${}^1S_0$
13	Al	$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p$				${}^2P_{0\frac{1}{2}}$
– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
17	Cl	$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^5$				${}^2P_{0\frac{1}{2}}$
18	A	$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^6$				${}^1S_0$
19	K	$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^6$		$4s$		${}^2S_{0\frac{1}{2}}$
20	Ca	$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^6$		$4s^2$		${}^1S_0$
21	Sc	$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^6$	$3d$	$4s^2$		${}^2D_{1\frac{1}{2}}$
22	Ti	$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^6$	$3d^2$	$4s^2$		${}^3F_2$
23	V	$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^6$	$3d^3$	$4s^2$		${}^4F_{1\frac{1}{2}}$
24	Cr	$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^6$	$3d^5$	$4s$		${}^7S_3$
25	Mn	$1s^2$	$2s^2$	20^6	$3s^2$	$3p^6$	$3d^5$	$4s^2$		${}^6S_{2\frac{1}{2}}$
– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –
29	Cu	$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^6$	$3\mathrm{d}^{10}$	$4s$		${}^2S_{0\frac{1}{2}}$
30	Zn	$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^6$	$3d^{10}$	$4s^2$		${}^1S_0$
31	Ga	$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^6$	$3d^{10}$	$4s^2$	$4p$	${}^2P_{0\frac{1}{2}}$
32	Ge	$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^6$	$3d^{10}$	$4s^2$	$4p^2$	${}^3P_0$
33	As	$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^6$	$3d^{10}$	$4s^2$	$4p^3$	${}^4S_{0\frac{1}{2}}$
– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –	– – –

rules which determine the J values of the levels are definite and reasonably simple, although the actual assignment of these values to a line in a complex spectrum is often difficult. The assignment can be made somewhat easier by the application of a magnetic field to the line. This results in the Zeeman effect with a splitting of the line into definite patterns of components dependent upon the J, L, and multiplicity values (Fig. 2.6). In general the different levels of a term have small separations and hence the lines in the observed spectra are often grouped as multiplets.

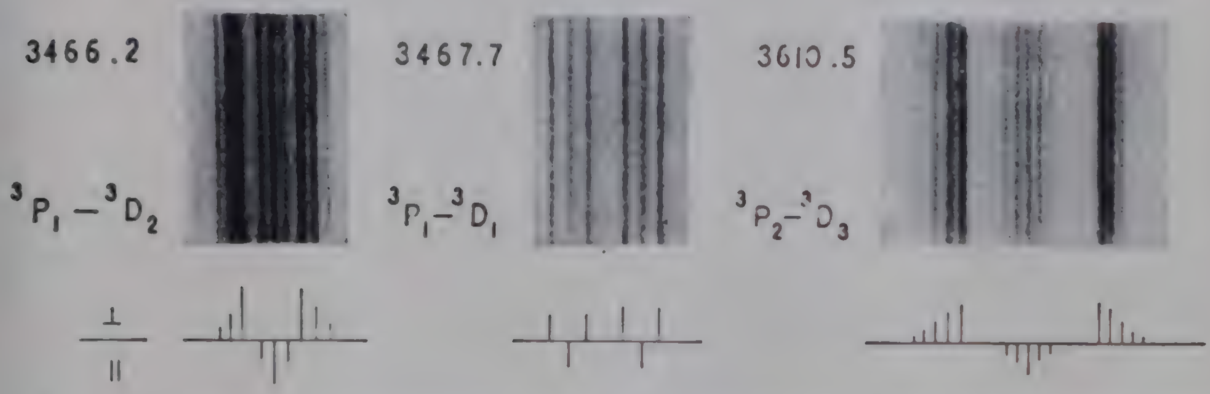


FIG. 2.6. Zeeman effect, indicating use of this method in the assignment of term values to spectrum lines. The example shown is the cadmium triplet 3466.2, 3467.7, and 3610.5 A (J. B. Green). N.

In the higher multiplicities as well as in the doublet system there are definite rules giving the relative intensities of the lines in a multiplet. In those elements showing higher multiplicities than doublets, there are two or more multiplicities, i.e., 1 and 3; 2 and 4; 1, 3, and 5; etc., so that the spectrum may be further complicated by transitions from terms in one multiplicity to terms in another in what might be called intersystem lines.

Only about half of the lines of the calcium spectrum are accounted for by the triplet-singlet systems together with their intersystem transitions. The remaining lines are due to the complete removal of one electron to yield a singly ionized calcium ion, which has an electron structure similar to that of potassium, and hence will produce a doublet system. Further ionization can take place with the removal of additional electrons as a result of higher excitation potentials or temperatures. Many of these higher states of ionization are available in our present laboratory methods, and are sometimes observed in the spectra of stellar bodies. An example of the similarity between series of spectral lines produced by atoms with the same number of electrons but different nuclear charge is shown in Fig. 2.7 (after Candler). The numerals after the element symbol indicate the spectra of atoms as follows: I, those

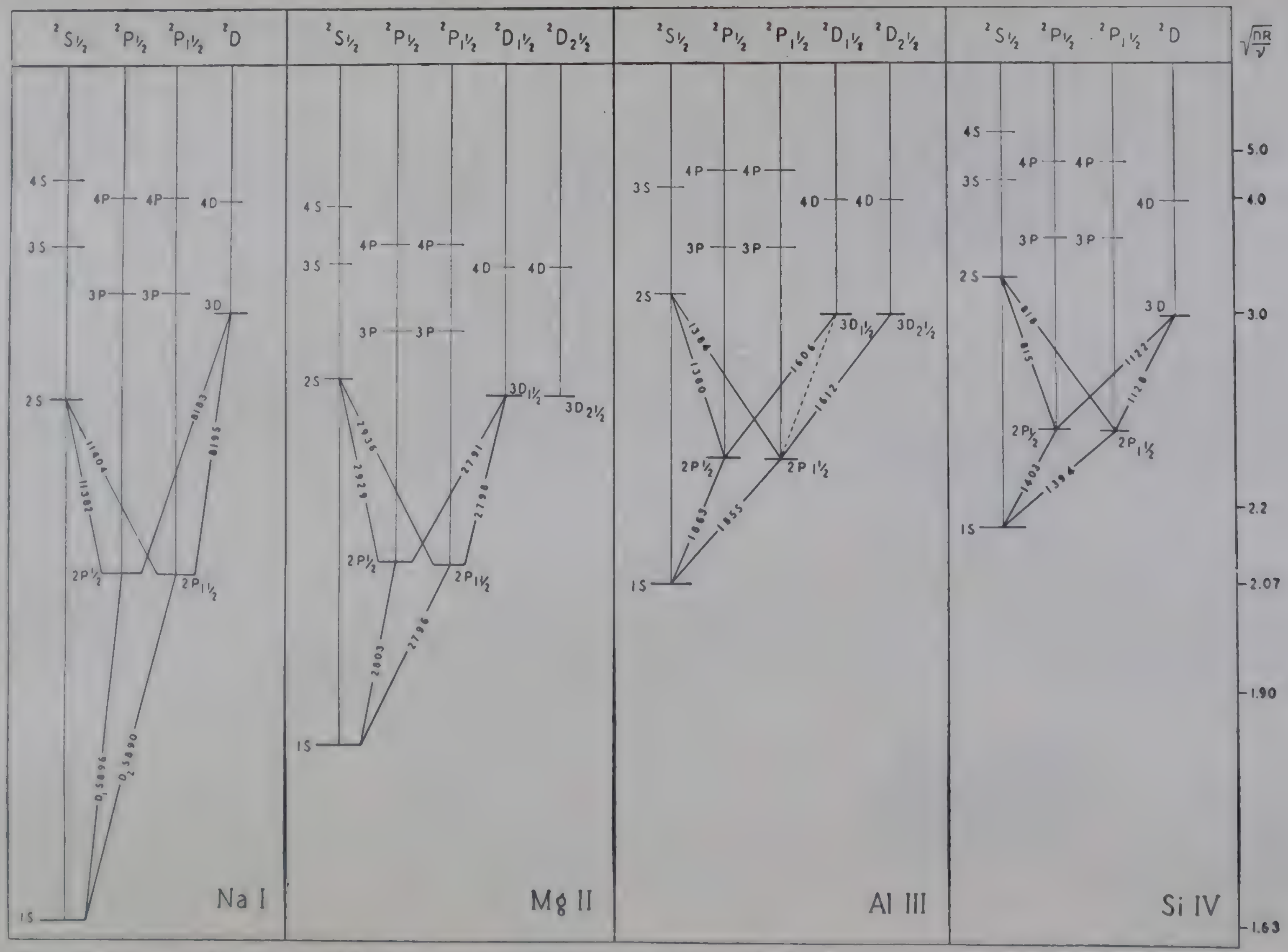

$^2S_{1/2}$ $^2P_{1/2}$ $^2P_{1\frac{1}{2}}$ ^2D
$^2S_{1/2}$ $^2P_{1/2}$ $^2P_{1\frac{1}{2}}$ $^2D_{1\frac{1}{2}}$ $^2D_{2\frac{1}{2}}$
$^2S_{1/2}$ $^2P_{1/2}$ $^2P_{1\frac{1}{2}}$ $^2D_{1\frac{1}{2}}$ $^2D_{2\frac{1}{2}}$
$^2S_{1/2}$ $^2P_{1/2}$ $^2P_{1\frac{1}{2}}$ ^2D
$\sqrt{\frac{nR}{\nu}}$
5.0
4.0
3.0
2.2
2.07
1.90
1.63
4S
3S
2S
1S
4P
3P
$2P_{1/2}$
$2P_{1\frac{1}{2}}$
4D
3D
$3D_{1\frac{1}{2}}$
$3D_{2\frac{1}{2}}$
11404
11382
8183
8195
$D_1$5896
$D_2$5890
2936
2929
2791
2798
2803
2796
1384
1380
1606
1612
1863
1855
818
815
1122
1128
1403
1394
Na I
Mg II
Al III
Si IV

FIG. 2.7. Level diagrams of four spectra arising in a system of 11 electrons, each system having a different nuclear charge. Ionization potential (∞S) for Na I = 5.12, Mg II = 15, Al III = 28.3, and Si IV = 44.95

which contain all their electrons; II, those which have lost one electron; III, those which have lost two electrons, and IV, those which have lost three electrons. A succeedingly greater voltage energy is required to produce a higher degree of ionization.

From the discussion of electron configuration it can easily be seen that the loss of an electron by ionization immediately changes the electron configuration to the preceding element in the periodic table, and, in a like manner, the normal state for this ionized atom and its multiplicity will follow the preceding assignment. Be I, with an outer electron configuration of $2s^2$ and normal state ${}^1S_0$, on ionization to Be II conforms to the Li electron configuration of $2s$ with a normal state of ${}^2S_{0\frac{1}{2}}$. The critical potentials for changes from state I to the ionized state II of the elements are indicated in Fig. 2.7. It will be noted that the inert gases have maximum ionization potentials, indicating that considerable energy is required to destroy the completed outer octet shell, while the alkali metals with but one electron in the outer shell are the easiest to ionize. The ionization potentials of the singly ionized elements (II) to the

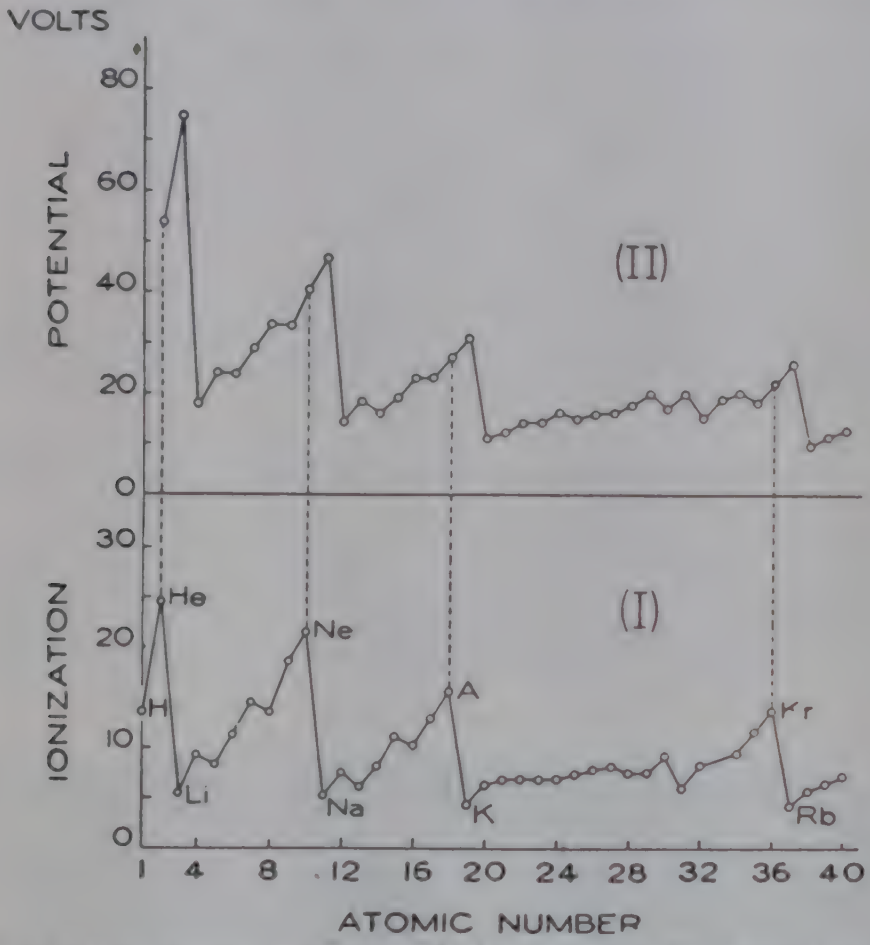


FIG. 2.8. Ionization potential of some of the elements (I) (lower) and ionization potential of these singly ionized elements to doubly ionized elements (II) (upper). Note, in II series, that zero voltage for each element is its single-ionization potential.

doubly ionized states (III) indicate again the stability of the octet she and the ease of liberation of the *s* electrons (Figs. 2.8 and 2.9).

As an example of higher ionization states, reference may be made t studies on argon (*C161*) in which the spectra of A III to A IX have bee studied. These higher ionization states are isoelectronic with unionize

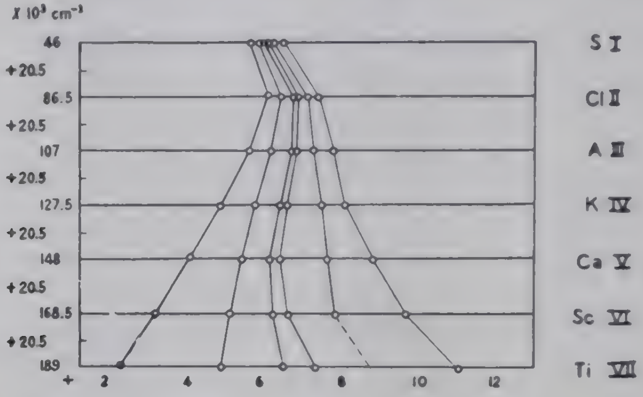


FIG. 2.9. Displaced frequency diagram in the sulfur I sequence showing regula frequency change in the $3s^2\,3p^4\,{}^3P - 3s\,3p^5\,{}^3P^0$ multiplet (Kruger and Pattin [*C119*]).

elements of lower atomic number, i.e., A V is isoelectronic with Si I; A VII is isoelectronic with Mg I; and A IX is isoelectronic with Ne I. Th corona ring at 5303 has been shown by Edlèn (*C78*) to be due to Fe XIV which is isoelectronic with Si I (Fig. 4.1*a*). The identity of the element and the ionization state can be determined from known spectra of atom of lower atomic number (Fig. 2.9).

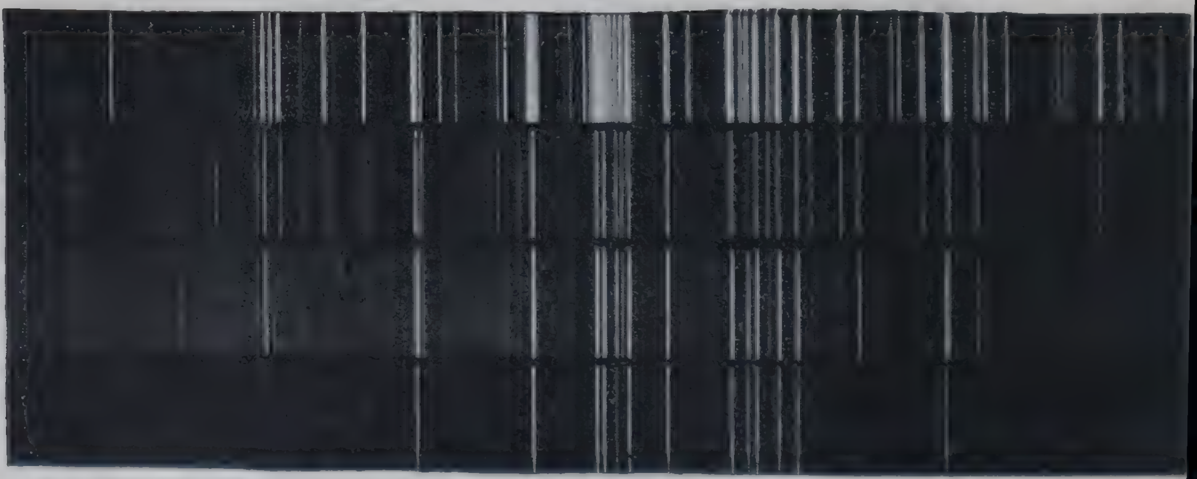


FIG. 2.10. Spectrogram of titanium (4300 A region) in arc (top) and furnace a 2600°, 2300°, and 2000° (Carnegie Institution of Washington, Mount Wilson Ob servatory). Note change in relative line intensities with variation of excitation du to lines caused by various ionization states. P.

Space limitations prevent the discussion of the complicated behavi of many elements. The system of spectrum formation which has bee described in the preceding pages may not always be followed with exact ness, except in the first few groups of the periodic table, and there are many instances of inversion, quantum defects, series perturbations, and autozionization.

The spectral-analysis method for isotopes by means of atomic spectra is difficult, and the theory involved in the explanation is too complicated to be adequately discussed in an analytical textbook (see section on band spectra).

The persistent or residual lines (strongest lines of the element) are important in qualitative analysis and have been shown to conform to certain rules with regard to electron configuration (See discussion on *persistent lines*, Chapter IV).

BAND SPECTRA (DIATOMIC)

The most widely observed band spectrum and one which causes considerable worry to the analytical chemist is the CN band system produced in a carbon arc in air (Fig. 2.11). In the study of a band spectrum we are dealing with the excitation of a molecule rather than a single atom, and the mathematical analysis becomes much more difficult than for an excited atom involving but a single central nucleus. With two or more nuclei within the excited body there will be inner vibrational, rotational, and electronic effects which will lead to variations from the single nucleus type, and because of the quantum effects these deviations will appear as regularly ordered satellite or band series. For purpose of nomenclature of the effects observed the symbols Σ, Π, Δ, and Φ are used in place of the *S*, *P*, *D*, and *F* terms of the atomic spectra system. The electron configuration is expressed in much the same manner (Table 2.6).

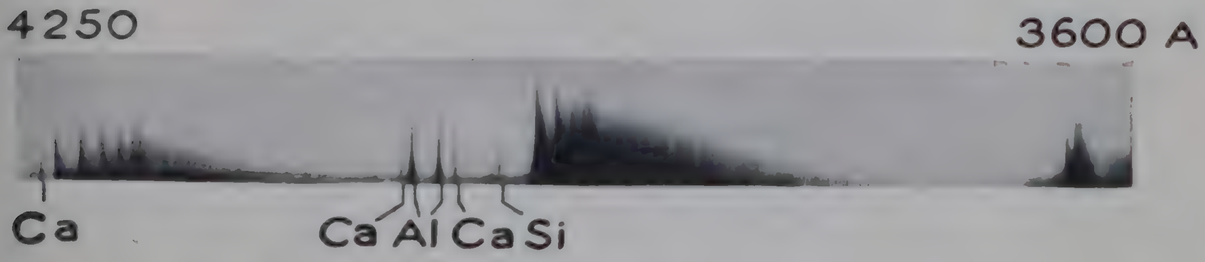


FIG. 2.11. CN bands (taken with a logarithmic sector to show relative intensity of band headings at 4216, 3883, and 3590 A corresponding to the 0–1, 0–0, and 1–0 bands.) N.

TABLE 2.6

Atoms					Molecule
C	$1s^2$	$2s^2$	$2p^2$	$^3P_0$	CO $1s\sigma^2$ $2p\sigma^2$ $2s\sigma^2$ $3p\sigma^2$ $2p\pi^4$ $3d\sigma^2$ $^1\Sigma$
O	$1s^2$	$2s^2$	$2p^4$	$^3P_2$	

On account of this increased complexity in spectrum analysis, practically all the work that has been done has been confined to diatomic molecules. The same general rules can be applied in the analysis of band spectra from diatomic molecules as have already been applied to the monatomic spectrum analysis. An atom or molecule can emit only discrete amounts of energy corresponding to certain states or energy levels and this energy can be related to the frequency of the emitted or absorbed radiation by the Bohr equation:

$$h\nu = E_2 - E_1$$

where E_1 and E_2 are the energy values of the two states or energy levels h, Planck's constant; and ν, the frequency of the absorbed or emitted radiation.

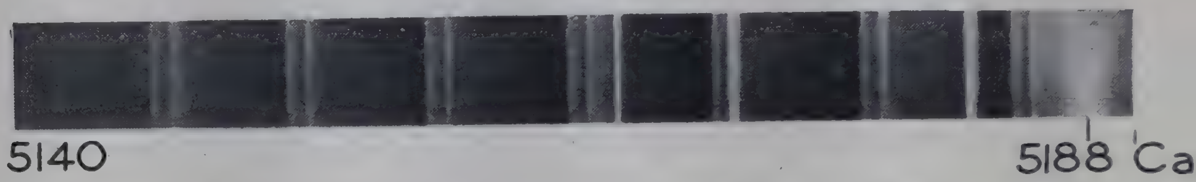


FIG. 2.12. CaF bands at 5145 A, (1–0) $^2\Sigma \longrightarrow {}^2\Sigma$. P.

ELECTRONIC, VIBRATIONAL, AND ROTATIONAL ENERGY

As in the atomic spectrum, emission corresponds to a transition from a higher to a lower energy state, and absorption to the transition from a lower to a higher state. This energy value which represents the difference between the two states may be further resolved, in the case of molecules, into three factors which are known as electronic, vibrational and rotational energy,

$$h\nu = E = E_e + E_v + E_r$$

The electronic energy, E_e, is similar to the energy of the simple atomic spectra, and involves a change in the orbit of one of the electrons in the molecule. The vibrational energy, E_v, is that produced from a change in the amount of vibration of two atoms along a line connecting them and can be defined by a single quantum number ($v = 0, 1, 2, 3, \cdots$) The rotational energy, E_r, involves a change in the energy of rotation about the center of mass of the molecule and is defined by a group of quantum numbers including the quantum number J which determines angular momentum. A qualitative representation of this system is shown in Fig. 2.13, in which $^1\Sigma$ and $^1\Pi$ represent electronic levels (corresponding to S and P levels of atomic spectra). The dotted horizontal lines represent ground states in the two levels, Σ and Π, while the quantum numbers represent the vibrational levels, and the quantum numbers J represent the rotational levels. In magnitude the electronic values are large and correspond closely to atomic effects. The vibrational effects are quite small as compared with the electronic, and the rotational are still smaller. Electronic bands are produced when there is a change (E_e) from one electronic level to another. Such bands involve vibrational, rotational, and electronic effects. When there is no change in electronic state ($E_e = 0$), the band systems produced are limited to vibrational and rotational effects. In this case the energy change is small and the bands will be limited to the near infrared. If the vibrational energy change is zero, then the only possible effects are in changes in the quantum number J, which will result in bands in the extreme infrared due to the very low rotational energy change. In vibrational bands two branches are

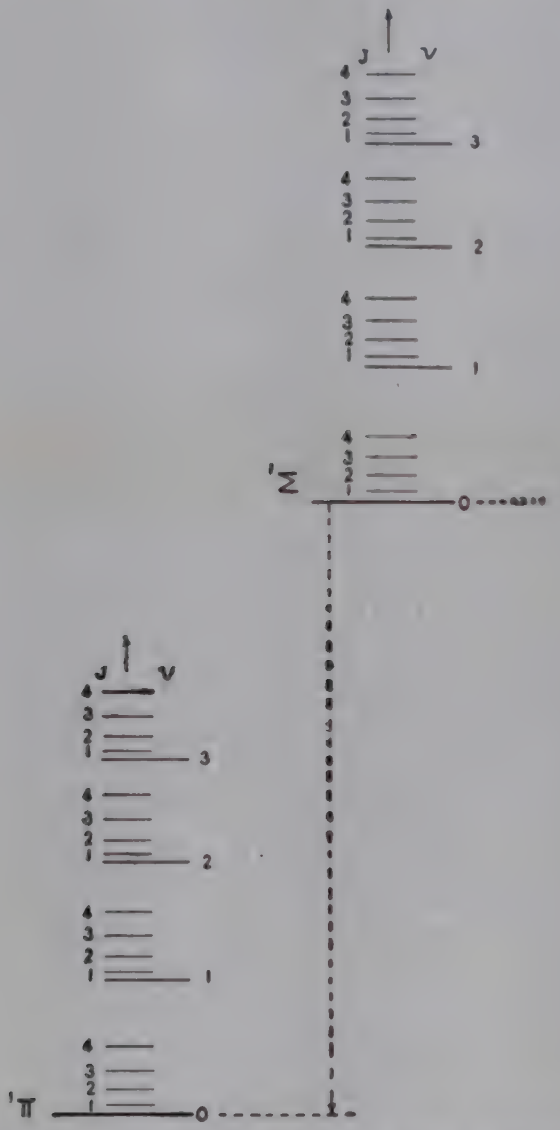


FIG. 2.13. Energy levels in the $^1\Sigma \longrightarrow {}^1\Pi$ band. Σ and Π indicate electronic states; $v = 0, 2, 3, 4, 5$, etc., indicate vibrational and $J = 0, 1, 2, 3, 4$, etc., indicate rotational states.

found: R, the positive branch, where J increases by 1; and P, the negativ branch, where J decreases by 1. The lines are thus indicated as R (4 to show a transition of J from 5 to 4 in emission and the opposite transition in absorption. The band origin line ($P(0)$) is a missing line but can be easily determined by extension of the P and R curves. A third type of band branch is the Q branch which occurs in electronic bands where the J value is unchanged in the transition. $J' = J''$ (Fig. 2.14). The direction of degrading will depend upon the relative energy values of the different levels.

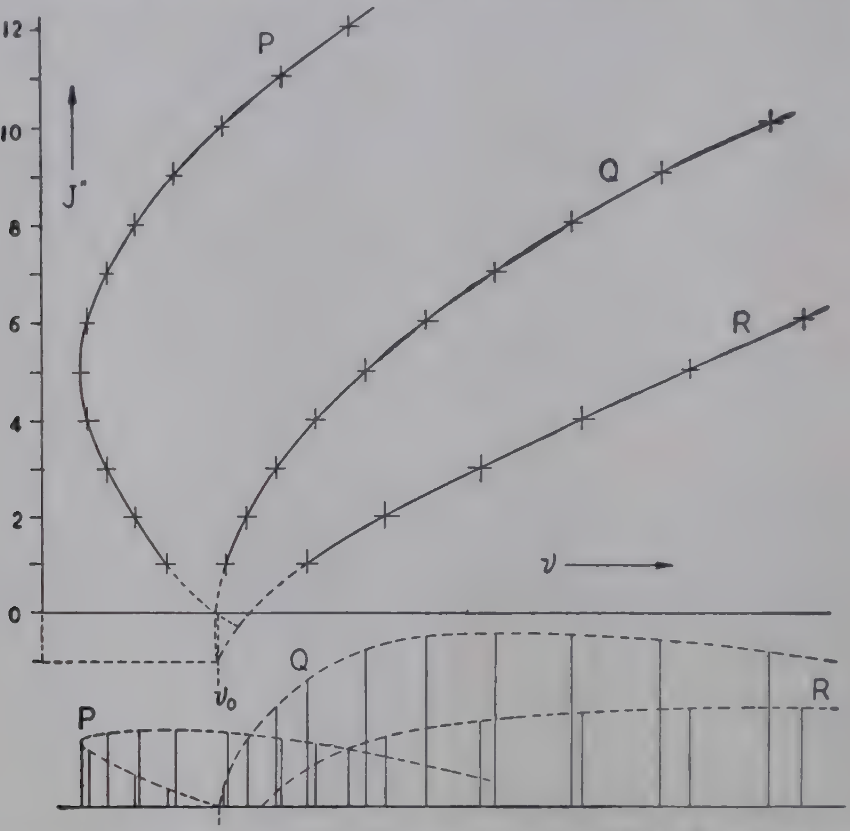


FIG. 2.14. Fortrat diagram of the $^1\Sigma \longrightarrow {}^1\Pi$ band of CO. P values correspond to electron shifts from n J levels in Σ to $n + 1$ levels in Π or a change of $+1$ in J. Q values correspond to a zero change in J and R to a -1 change in J. All P, Q, and R values in this diagram originate in the same level in Π and terminate in the same ν level in Σ. If the ν level in Σ is 0 and in Π is 0 the band is known as the 0, 0 band, and correspondingly if the electron shifts are from $v = 1$ in Σ to $v = 0$ in Π it will be known as the 1, 0 band.

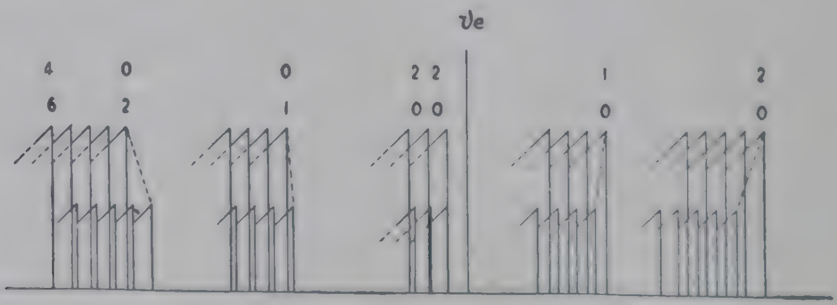


FIG. 2.15. Isotope displacement in band spectra.

Although the theory of band spectra like the theory of atomic spectra is not being considered in detail in this book on applied spectroscopy, a fuller expansion with regard to the theory of band spectra has been made on page 144 as a part of the discussion of absorption spectra.

ISOTOPE EFFECT

Of particular interest to the chemist is the application of diatomic band spectra to the identification of isotopes. While electronic level displacement alone does not show appreciable differences, the added vibrational energy will cause a marked shift since the vibrational band is associated with vibrations whose energy depends on the actual masses of the two nuclei. Band structure in the stronger of the isotopic members, however, will often mask the presence of a weaker isotope band series unless the band head of the less abundant molecule lies outside that of the more abundant molecule (Figs. 2.15 and 2.16).

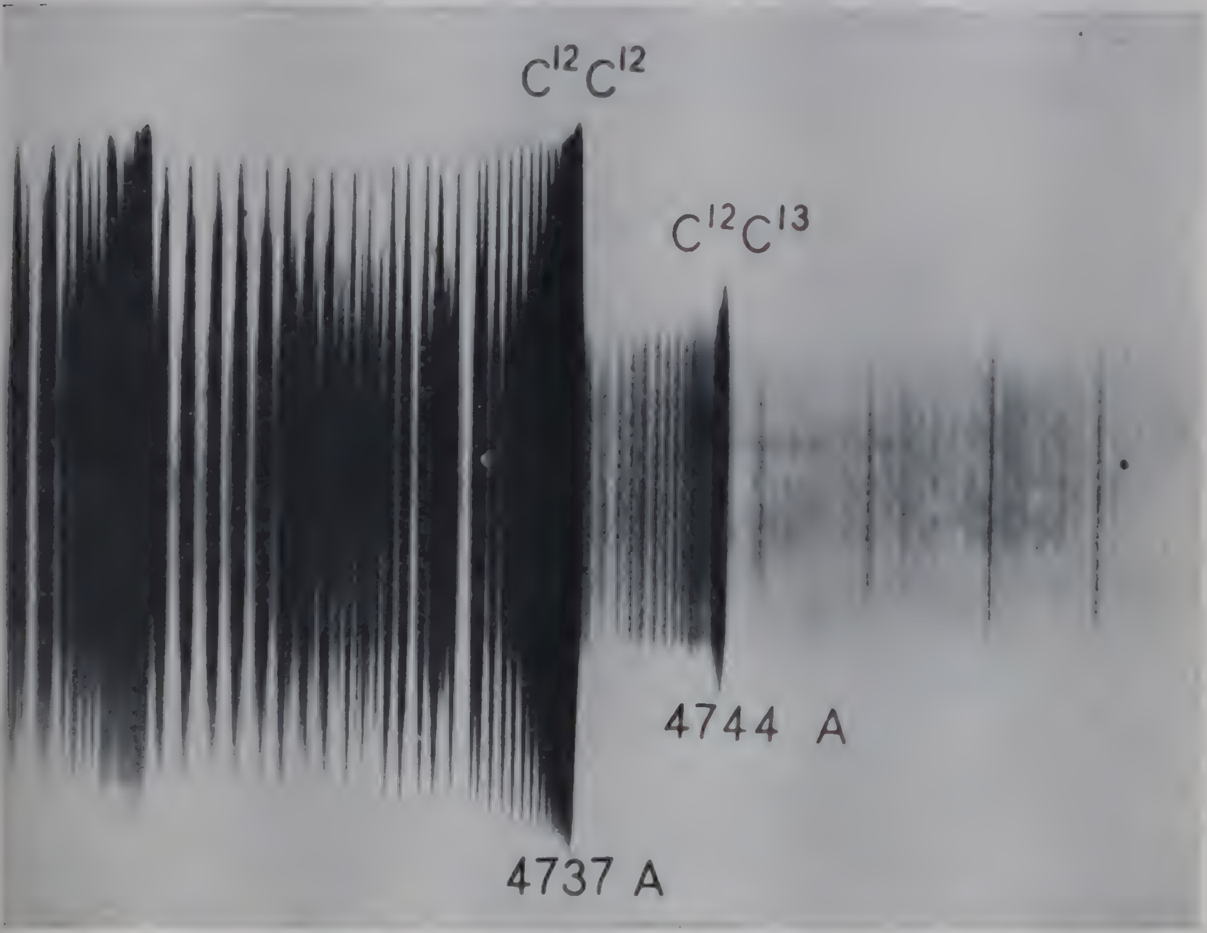


FIG. 2.16. Isotope effect of C^{13} in the C_2 band (1–0) spectrum (Birge and King). **N.**

Though not included within the scope of this book, it can at least be mentioned that the spectral studies of diatomic molecules can be applied to the determination of numerous important physical constants such as the heat of dissociation, ionization potentials, predissociation effects, and isotope concentration.

LITERATURE

General

A. C. CANDLER, "Elements of Atomic Spectrum Theory" (*A10*).
A. C. CANDLER, "Atomic Spectra," Vols. I and II (*A9*).
R. C. JOHNSON, "Spectra" (*A51*).
G. HERZBERG, "Atomic Spectra and Atomic Structure" (*A41*).
F. TWYMAN, "The Spectrochemical Analysis of Metals and Alloys" (*A95*)
S. GLASSTONE, "Text-Book of Physical Chemistry" (*A32*).
R. C. GIBBS, "Line Spectra of the Elements" (*C89*).

Reference

WHITE (*A103*), BALY (*A4*), JEVONS (*A50*), SCHEIBE (*A81*), GROTRIAN (*A33*), KRONIG (*A60*), GLASSTONE (*A31*), SOMMERFELD (*A87*).

CHAPTER III

EMISSION SPECTRA (APPARATUS)

SPECTROSCOPES AND SPECTROGRAPHS

The spectroscope has been developed from the observation of Newton in 1666 that white light in passing through a prism was dispersed into a spectrum. (By spectrum is meant the ordered arrangement of radiation in accordance with its frequency or wavelength.) Newton did not use a narrow slit for his illumination source, and so it remained for Wollaston and Fraunhofer (1802–1817) to make the observation that light sources such as the sun were not homogeneous, but involved light and dark spectral regions. Fraunhofer measured carefully the dark lines in the sun spectrum and indicated the more important lines by letters (Fig. 4.1*a*). This system of nomenclature is still used for these lines, such as the D, or yellow, sodium line. (See Frontispiece, Plate I.) These dark lines in the sun spectrum are due to absorption of continuous radiation by vapors of the elements. By the comparison of the angle of bending of the light path with the wavelength of the light, we can establish a dispersion curve for the refracting substance. From the dispersion curve (Fig. 3.1) it can

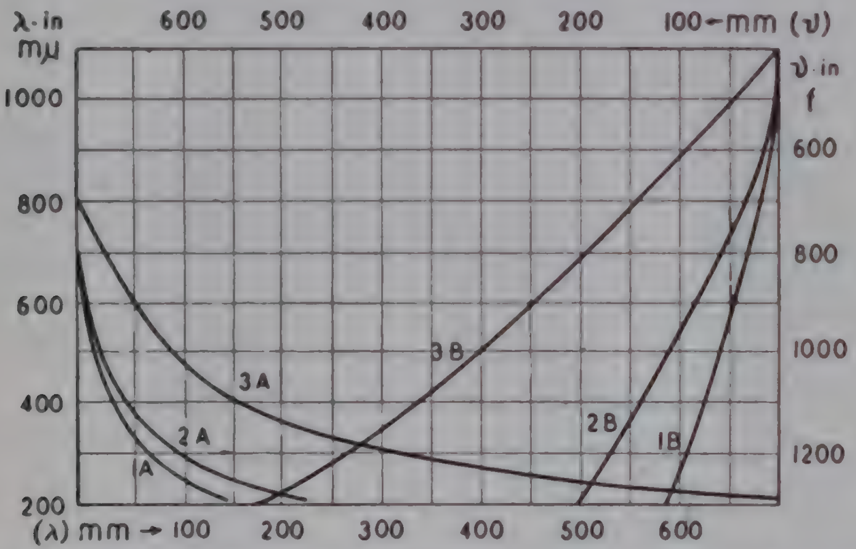


FIG. 3.1. Dispersion curve for quartz spectrographs; *A*, against wavelength scale; *B*, against frequency scale. *1.* Small Littrow (30 cm). *2.* Medium Cornu (70 cm). *3.* Large Littrow (180 cm).

be seen that the separation is not linear, and hence, in the use of such materials as glass and quartz, it will be necessary to bend the photographic plate to approximately the same curvature to record the spectrum at proper focus. This change in dispersion rate and focal point can be made more linear by means of a compound lens system in what is known as the focusing lens of the instrument.

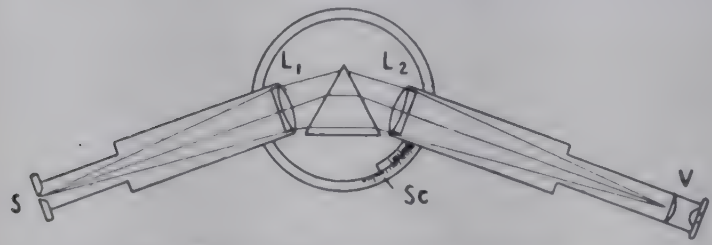


Fig. 3.2*a*. Bunsen spectroscope.

The discovery of the extension of the spectral region beyond the visible to infrared and ultraviolet regions dates from the work of Herschel in 1800 (infrared) and of Ritter in 1801 (ultraviolet).

Fraunhofer first applied the principles of diffraction of light from a ruled grating (his grating was made of fine silver wires) to the measurement of dispersion angles, and, by reason of the linear dispersion obtained in a grating, was able to assign actual wavelength values to the lines which he had identified in the sun absorption spectrum. Both these methods of light dispersion have been employed in subsequent spectroscopic investigations, and the choice of a dispersion system in present-day spectroscopic studies is still largely a matter of personal preference, availability, and cost.

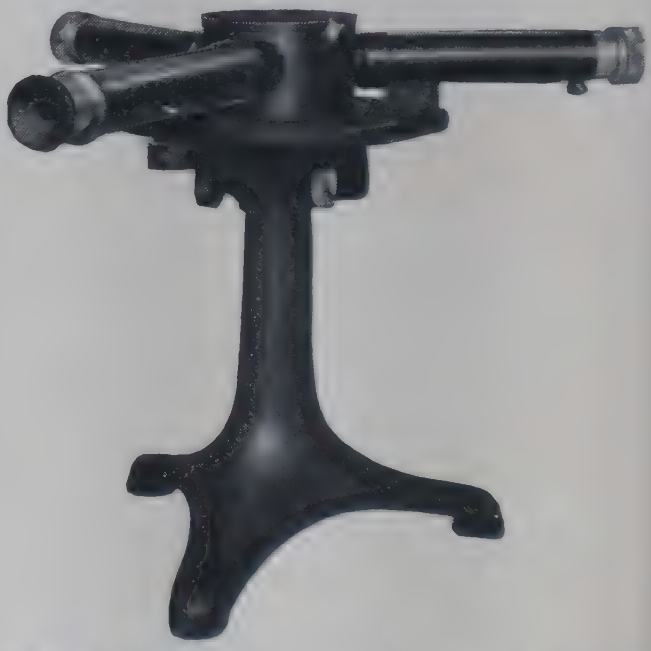


Fig. 3.2*b*. Spectroscope, telescope tube in front, collimator tube and slit on the right, scale illuminating tube left (rear) (Gaertner).

The simple spectroscope as devised by Bunsen (Fig. 3.2*a*) involves a slit (*S*), collimating lens (L_1), refracting prism (a 60° prism of quartz, glass, or other refracting medium), a focusing lens (L_2), and an eyepiece (*V*). Through this eyepiece it is possible to examine the spectrum so long as it remains within the visible range. For extension beyond the visible, the recording of the complete spectrum, and the study of faint lines whose intensity is not sufficient to produce a visual effect, but whose integrated intensity over a period of time would be sufficient to produce a photographic effect, a modification of the spectroscope has been devised, namely, the spectrograph (Fig. 3.3), which utilizes a photographic emulsion for the recording of the spectrum. Because the lens systems involve the principle of refraction of light as a means of focusing, and the physical phenomena of dispersion upon which the whole spectrographic principle is based, it is apparent that the focal length of a simple lens or system will be shorter for those rays which are bent at

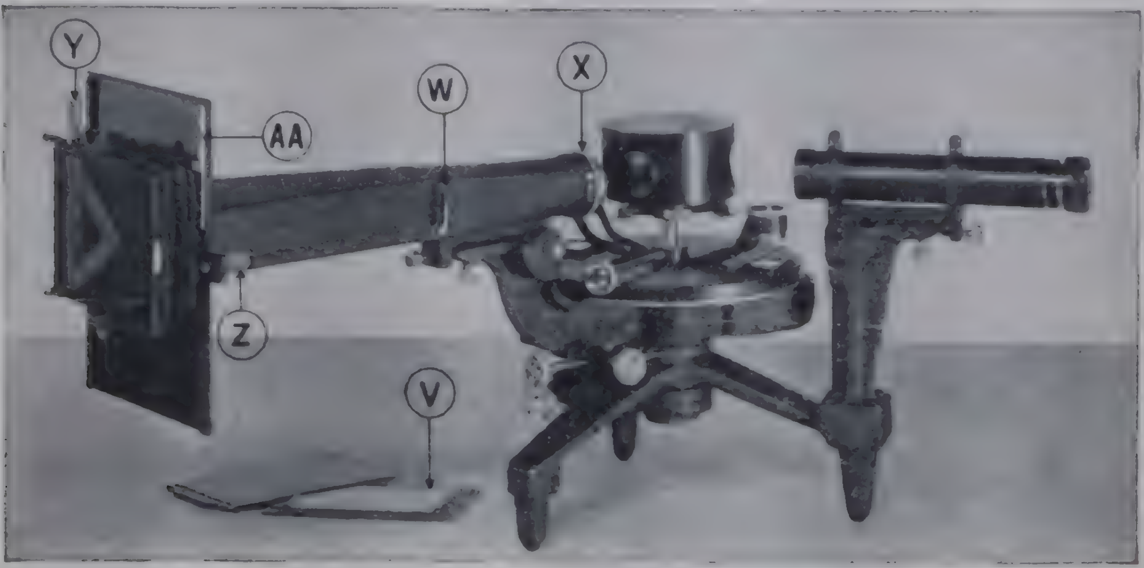


Fig. 3.2*c*. Student spectroscope with camera attachment to convert instrument into a spectrograph (Spencer Lens Company).

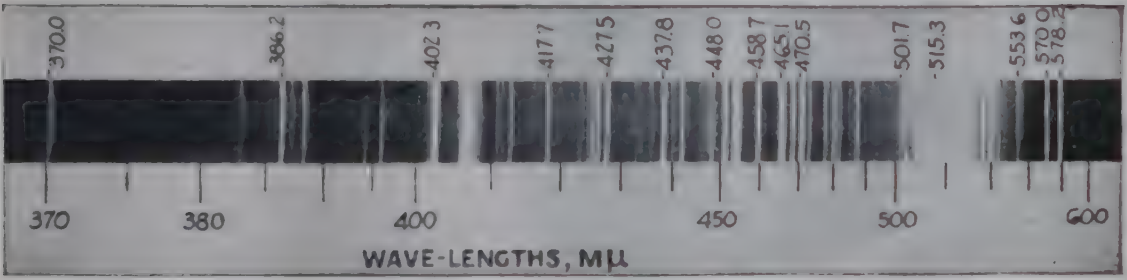


Fig. 3.2*d*. Spectrogram taken with the spectrograph shown in Fig. 3.2*c* (Spencer Lens Company).

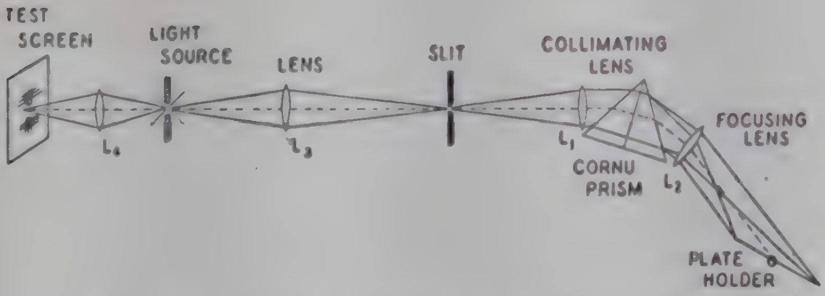


Fig. 3.3. Optical diagram of a spectrograph.

a greater angle. We may, therefore, expect a change in focal length and dispersion rate on the photographic plate which will approximate the dispersion curve of the refracting medium (Fig. 3.1).

A partial correction of the necessary curvature of a photographic plate may be made by means of a suitably selected set of lens components in the focusing lens, just as one may correct the focal points of a photographic lens, so that various wavelengths of light will have the same focal point, in what is known as an achromatic lens. In this correction no attempt is made to alter the slope of the plate with regard to the normal beam from the prism, but rather to reduce the curvature of this focal plane so as to avoid too severe a bending of the photographic plate. Even with this applied correction it is often necessary to use very thin

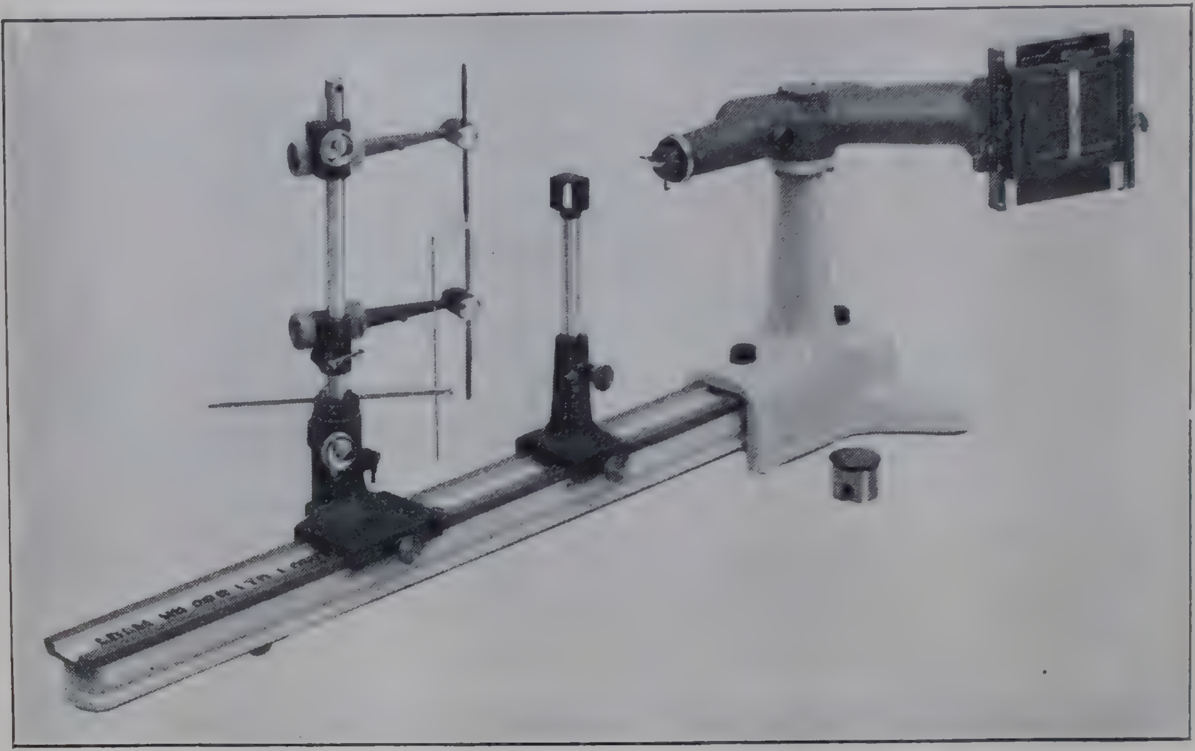


FIG. 3.4*a*. Hilger spectrograph, 20 cm (small).

Note: In order to indicate spectrograph sizes, in this book the following notations of small, intermediate, medium, large (sometimes indicated as Littrow, without designation of size), and extra large are used:

DESIGNATION	FOCAL LENGTH (F_D)	SPECTRUM LENGTH 2000–8000 A	NEGATIVE SIZE
Small	20 cm	8 cm	4¼ inch
Intermediate	40	14	7 inch
Medium	60–75	22–25	10 inch
Large	150–180	60–80	10 inch (3×)
Extra large	300	120	10 inch (6×)

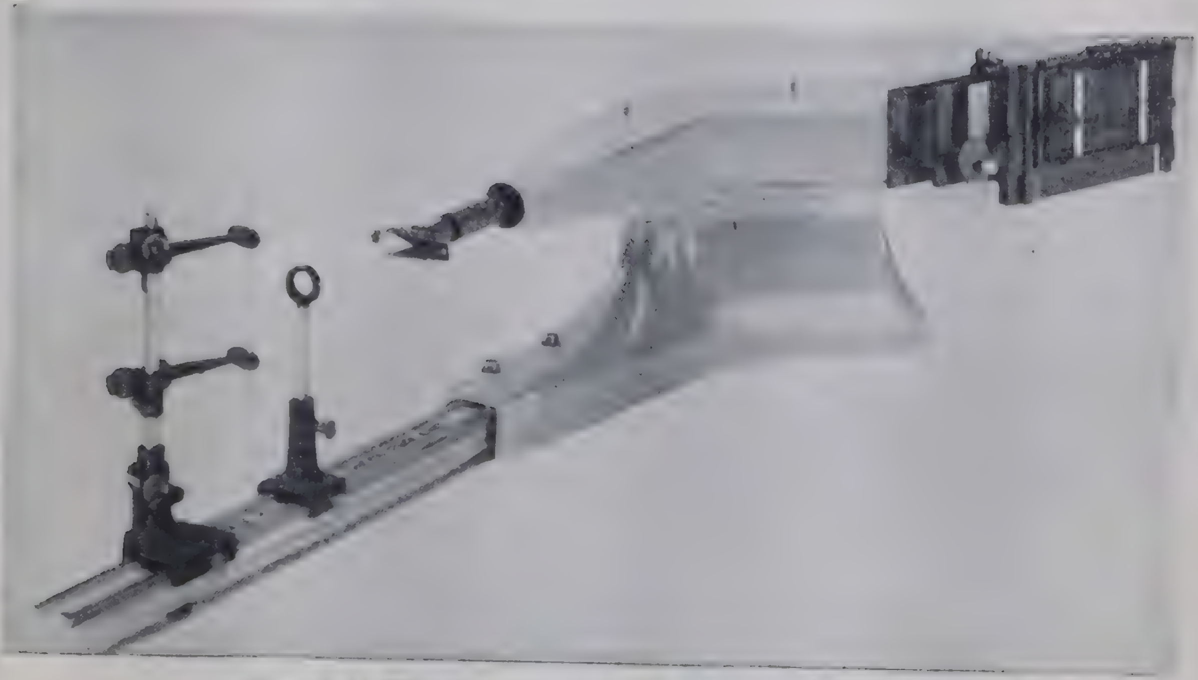


FIG. 3.4*b* Hilger spectrograph, 60 cm (medium).

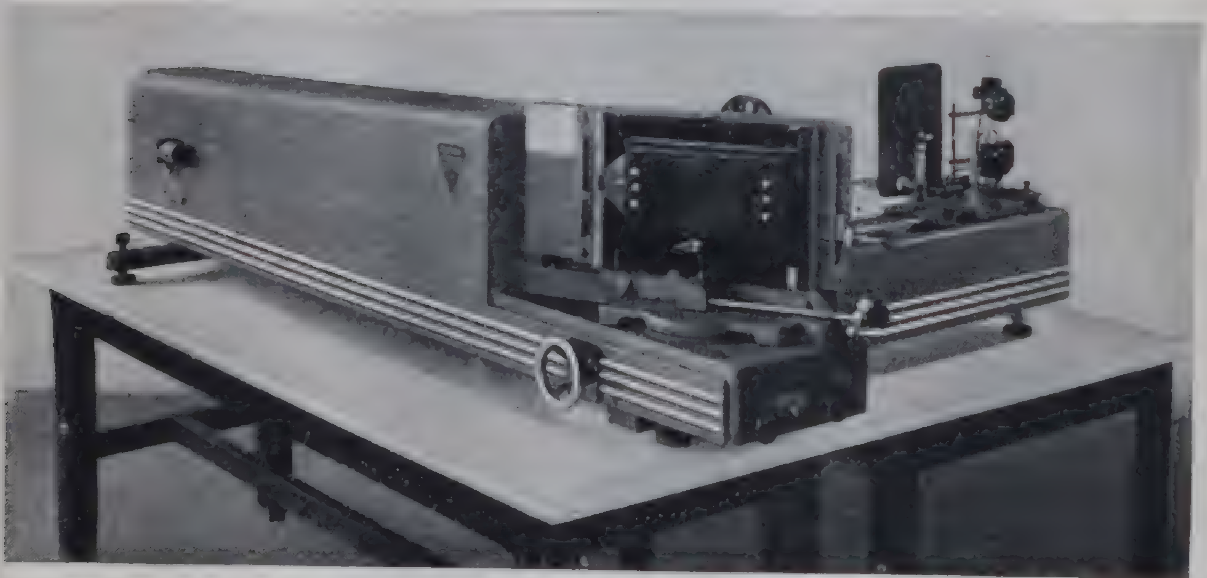


FIG. 3.4*c*. Bausch and Lomb spectrograph, 180 cm (Littrow).

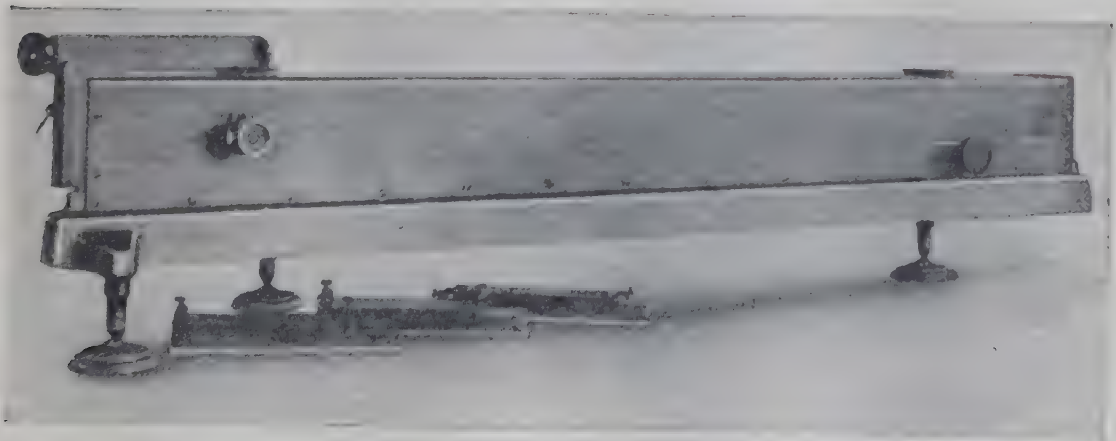


FIG. 3.4*d*. Gaertner spectrograph, 170 cm (Littrow).

glass plates or film base for the photographic emulsion rather than the usual photographic plate, which could not stand the bending strain.

The spectroscope or spectrograph is most efficient when the incident and refracted beam form the same angle with the prism—the angle of minimum deviation. Most spectrographs are so constructed that this angle is formed between the middle of the spectrum plate and the prism face, and the slit and the prism face (Fig. 3.3). The object of the collimating lens (L_1) is to bring the light into a parallel beam as it passes through the prism (P) and thus cause the beam to strike the prism at a uniform angle so as to produce the same dispersion, at any wavelength, for all parts of the beam. The focusing lens (L_2), as has been mentioned, brings the parallel dispersed beams into focus on the photographic negative placed at the focal plane.

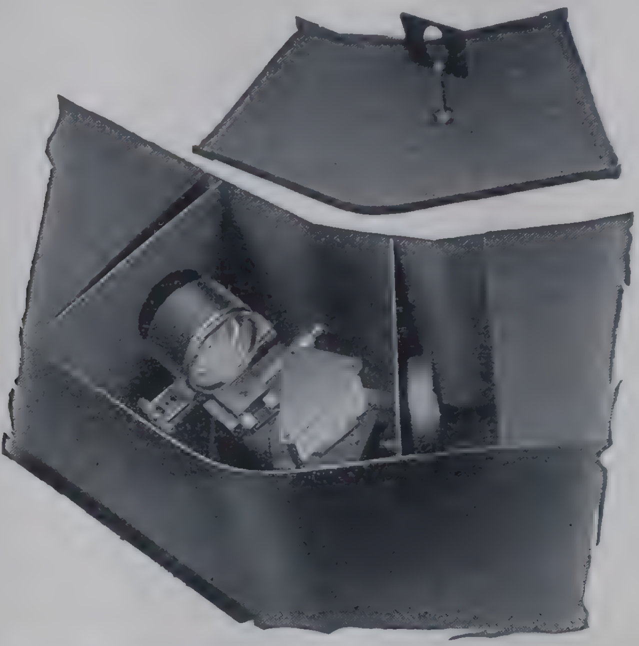


FIG. 3.5. Lens and prism assembly (medium Bausch and Lomb spectrograph).

CONSTANT-DEVIATION SPECTROMETERS

For visual inspection of emission spectra and a study of visual absorption spectra, one may use the simple Bunsen spectroscope or the more convenient constant-deviation spectrometers (Figs. 3.6*a*, 3.6*b*, and 3.10*a*). The usual constant-deviation spectrometer has a combination 30-90-30° prism (Fig. 3.11*A*), although some instruments are available in the Wadsworth mounting (Fig. 3.11*B*), or a right-angle prism and a grating replica (3.11*C*). In the usual visual spectrometer, the operating drum is graduated in millimicrons, and in most instruments a variable slit width in provided in the eyepiece so that a considerable portion of the spectrum can be seen at one time, or the slit can be narrowed to the width of a single line. Because of stray light which may be a bother in making readings at the blue and red ends of the spectrum, many instruments have a built-in red and blue filter so as to cut out a considerable portion of the stray light.

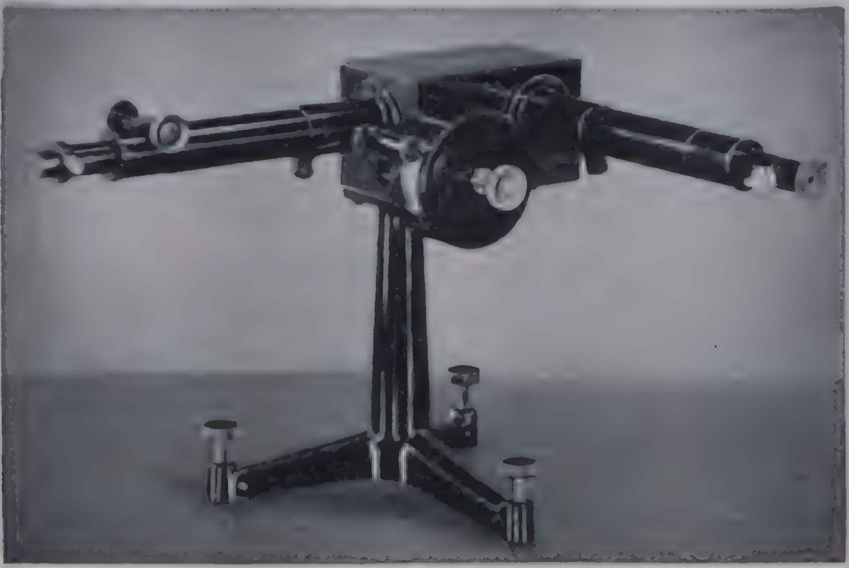


FIG. 3.6*a*. Spectrometer (Bausch and Lomb).

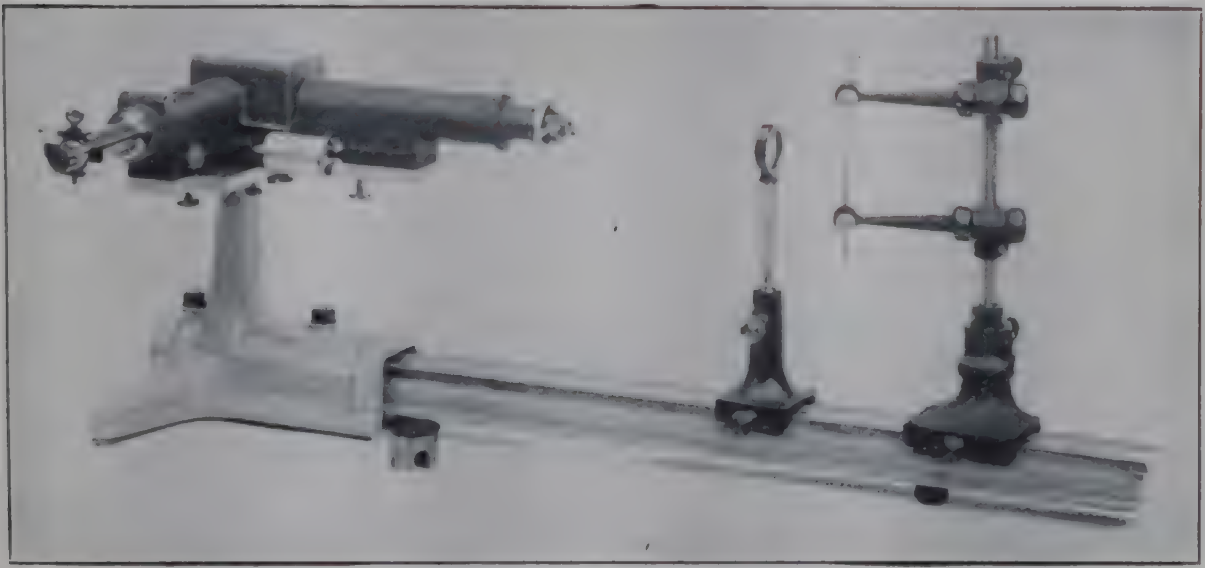


FIG. 3.6*b*. Spectrometer (Hilger).

Where an ultraviolet spectrometer or monochromator is desired in order to furnish a high intensity of monochromatic radiation, the usual type of instrument employed for this purpose is the double prism type such as the van Cittert (Fig. 3.14), Bausch and Lomb (Fig. 3.15), Gaertner, or Hilger.

Prisms

Certain modifications of the simple instrument described above have been developed, among which the Littrow spectrograph is outstanding in importance. This modification (Fig. 3.7) utilizes a 30° prism with a mirror-back face; the beam of light passes through the prism to the mirror face and is reflected back through the prism, the total path thus being equivalent to a 60° prism (Fig. 3.8a). Certain natural products, such as quartz crystals, are sometimes used as the refracting medium; the nature of the crystal structure is such as to require the cutting of the refracting prism along certain definite optical axes, and, except for that light which is refracted at exactly the angle of minimum deviation, there will be a doubling of the image due to the optical properties of

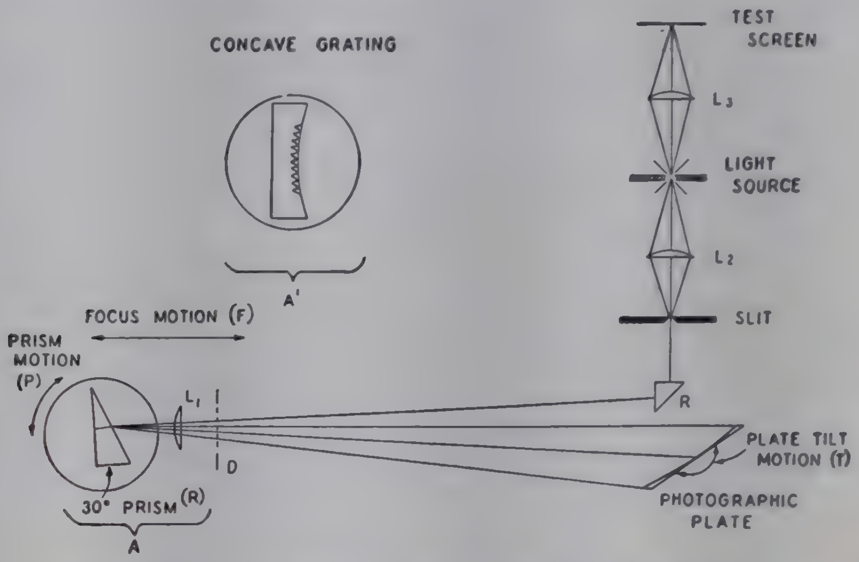


Fig. 3.7. Diagram of Littrow spectrograph (see Exercise 3, Chapter XII, for a description of parts and adjustment).

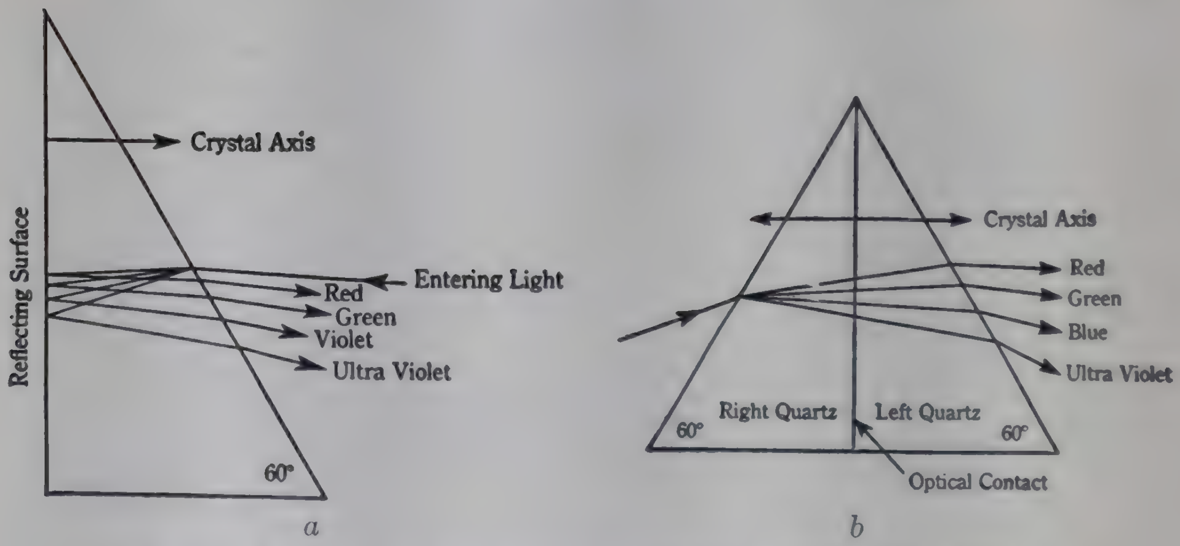


Fig. 3.8. Littrow (a) and Cornu (b) prisms (Bausch and Lomb).

quartz. To correct for this, Cornu has devised a prism which bears his name (Fig. 3.8*b*), in which the 60° prism consists of two halves of 30° each in optical contact and composed of quartz of opposite rotatory power, i.e., one dextro and one levo prism; this results in a complete correction of the defect. In the Littrow modification it is not necessary to apply such a correction, as the reversal of the beam by the mirror surface and the return of the beam through the same prism results in a correction of this doubling effect (Fig. 3.7).

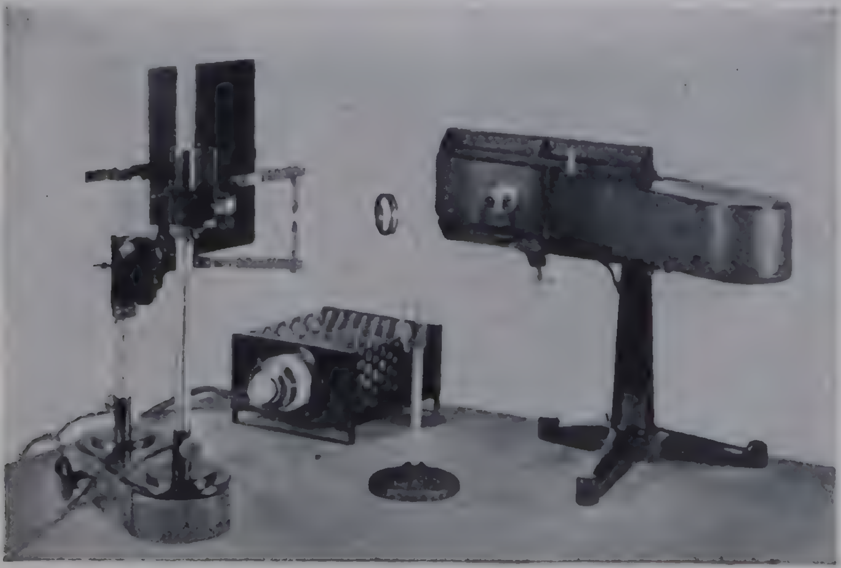
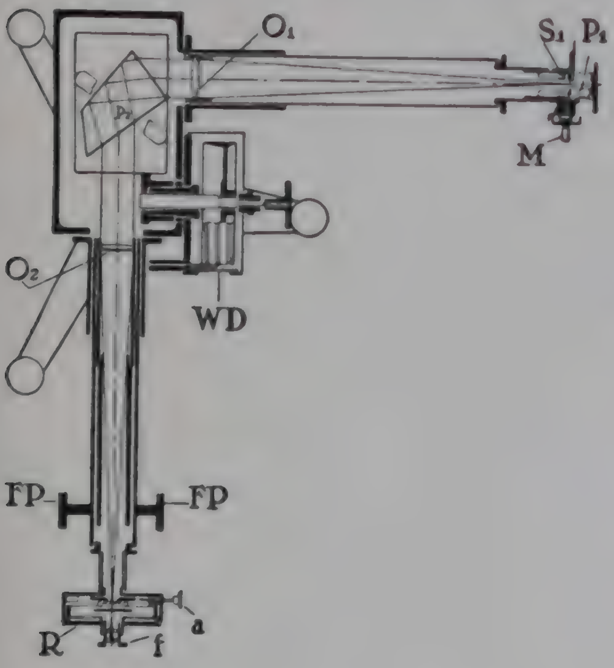


FIG. 3.9. Small Littrow (Bausch and Lomb) (30-cm focal length—210 to 700 mμ in 15 cm).



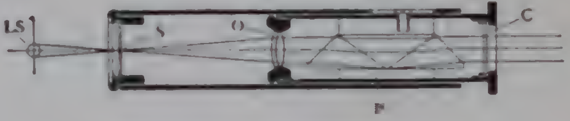


FIG. 3.10*a*. (left) Diagram of constant-deviation spectrometer. S_1, slit; P_2, constant-deviation prism; $W\ D$, wavelength drum; F, eyepiece.

FIG. 3.10*b*. (above) Hand spectroscope. O, collimating lens; S, slit; P, prism (Bausch and Lomb).

Among the other modified prism instruments are constant-angle and direct-vision spectroscopes and spectrometers (Fig. 3.6). A spectrometer supplies light of a constant frequency from a homogeneous source and may be considered an instrument for measuring the frequency or wavelength of the observed heterogeneous source. Two constant-deviation prisms are shown in Fig. 3.11, in which the refracted beam is reflected either by a right-angle prism (*A*) or a plain mirror (Wadsworth mounting) (*B*). The result of this reflection is to reverse the spectral order so that a constant angle is obtained for all wavelengths at the angle of minimum deviation of the prism.

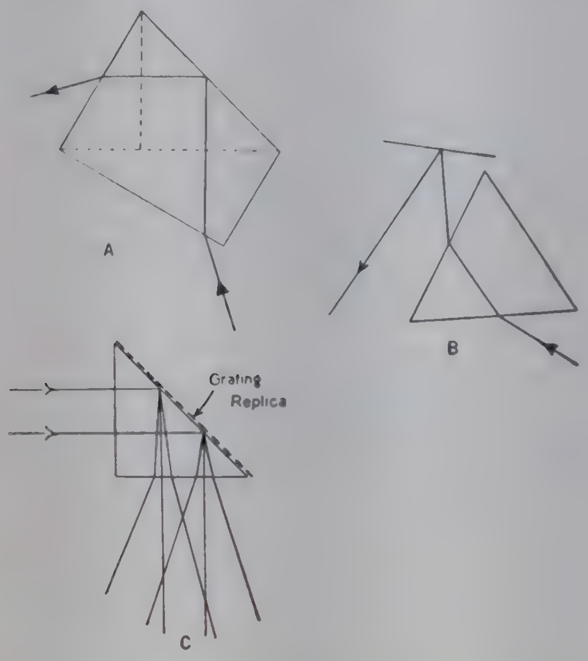


FIG. 3.11. Dispersion prisms.

A. 90° constant-deviation prism (Pellin-Broca type).

B. Wadsworth constant-deviation mounting.

C. Right-angle prism with grating on reflecting face.

COLLIMATING AND CONDENSING LENSES

Spectrographs of the Cornu (60°) type will have a two-lens system involving a collimator lens facing the slit and a focusing lens facing the plate holder. In most instruments little or no attempt is made to correct the lens system achromatically, which results in the plate holder being set at a distinct angle to the light beam, the longer-wavelength end of the plate holder being further from the prism than the short-wavelength end. However, considerable detail is paid to correction of spherical aberration, and in the more expensive instruments the lenses are carefully computed with non-spherical surfaces. The non-achromatized lens system which requires the tilting of the photographic plate is of distinct advantage in that it increases the dispersion on the photographic plate. Some attempt is made in the calculation of the lens system to produce a focal plane which is as nearly as possible linear so as to avoid too sharp a curvature for the photographic plate. Many instruments require photographic plates of thin glass in order to conform to the curvature, and on special order most photographic manufacturers will supply plates on extra-thin glass. In the Littrow type of spectrograph a single lens is used, and since this lens must act both as a collimating and focusing lens it is more difficult to correct aberration effects. However, on instruments of the Littrow type the *f*-aperture is seldom more than *f*-20 as compared with a *f*-8 to *f*-11 value for the medium type of Cornu-prism instrument. In most instruments diaphragms are provided for the collimating and focusing lenses, and, where adequate correction in the lens system is not provided, these may improve the line definition, although this may be at the expense of the resolving power and require additional exposure.

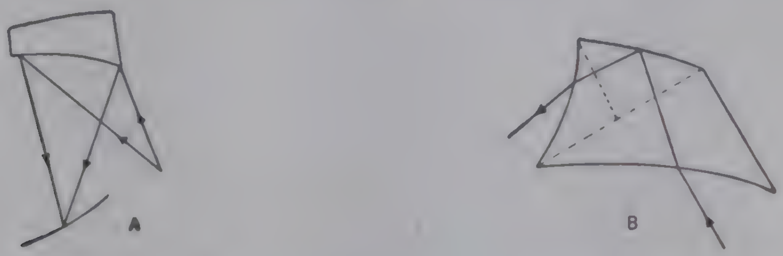


FIG. 3.12. Combination lens and prism systems.
A. Féry *B*. Callier.

GRATINGS

With the recent development by Wood of a rapid and accurate method of ruling on glass and aluminum, and the ability to aluminize glass gratings, this form of dispersion for spectrographs is being used to a much greater extent than in the past. Of the various methods of mounting a grating, the most generally accepted forms for chemical analysis are known as the Eagle and Roland mountings. The Eagle mounting is quite similar to the Littrow mounting for a prism spectrograph, and, in fact, there are available on the market instruments with interchangeable grating and prism systems (Hilger—185) (Fig. 3.7*A*′). The grating, in itself, is only a dispersion medium, and it is still necessary to use a collimating and focusing lens. As in the Littrow-mounted prism instrument, the same lens may function both as a collimating and focusing device. As a further simplification, in both the Eagle and Roland-mounted grating and the Littrow-mounted prism instruments, a combination lens and dispersion piece has been devised. In the grating instrument this involves the use of a concave mirror as the lens system, upon the surface of which the grating is ruled. Such a grating is generally called a concave grating, and because of the uniform reflection of light regardless of wavelength it acts as a fully corrected achromatic lens system. In the prism instrument the effect is produced by grinding both the front and back of the prism as two lens surfaces with an angle of 30° between the arcs formed by the two curved surfaces (Fig. 3.12*A*). This prism, which is known as a Féry prism, though very economical of quartz is not extremely satisfactory on account of its inability to produce an achromatic lens effect.

In addition to the grating spectrographs shown in Figures 3.13*a*, 3.13*b*, and 3.13*c*, new grating spectrographs have recently been announced by Jarrell-Ash, Bausch and Lomb. and Adam Hilger.

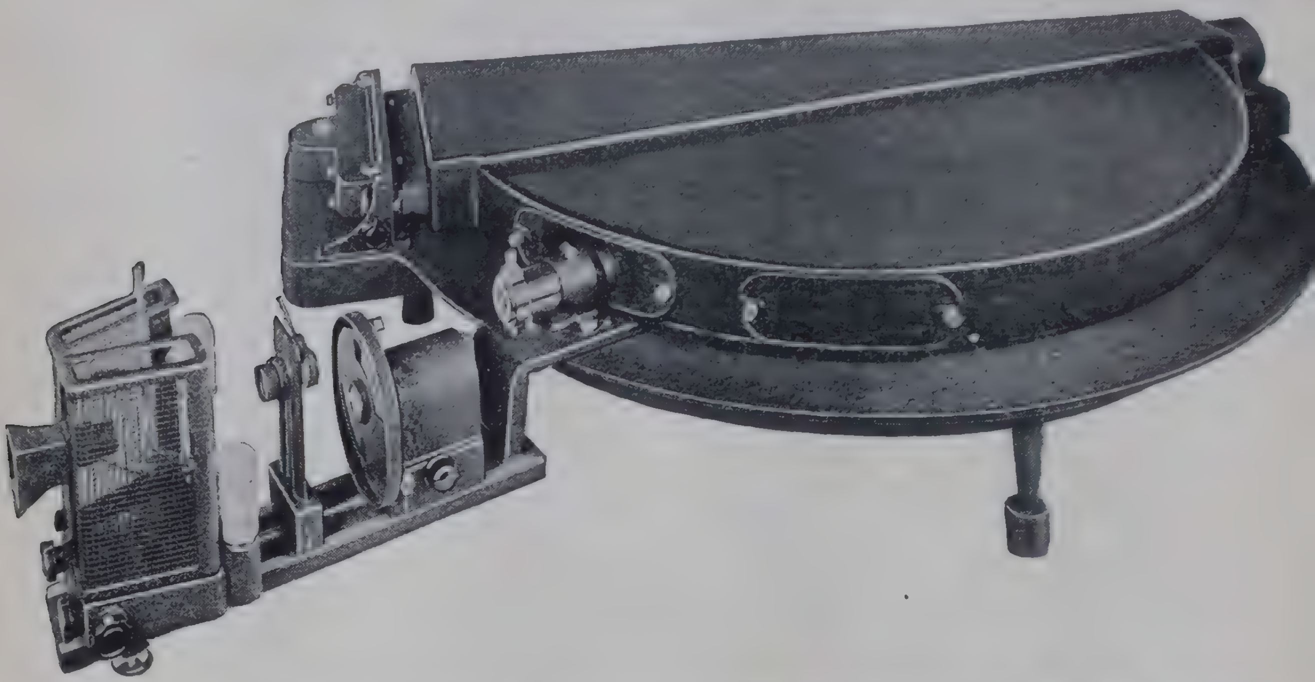


Fig. 3.13*a*. Applied Research Laboratories grating spectrograph (H. W. Dietert Company).

Concave gratings, by reason of their optical principle, do not produce a spectrum of stigmatic characteristics, and the image produced on the plate is not a photographic image of the slit but rather an integrated and redistributed image of the slit intensity. This prevents the use of a step sector or slit diaphragm at the slit, although a similar diaphragm has nearly equal effectiveness at the plate (Fig. 3.13). A diaphragm or step sector can be introduced between the light source and the slit and can be so positioned as to produce a sharp horizontal image on the photographic plate. This position is at the secondary astigmatic focus which lies between the usual position of the source and the slit.

The choice of dispersion medium is dependent in part on the spectral range to be covered. For the photographically sensitive region of the ultraviolet, quartz is the most acceptable; for the near ultraviolet and visible, glass and gratings; and for the infrared, rock salt or sylvite crystals and gratings may be used.

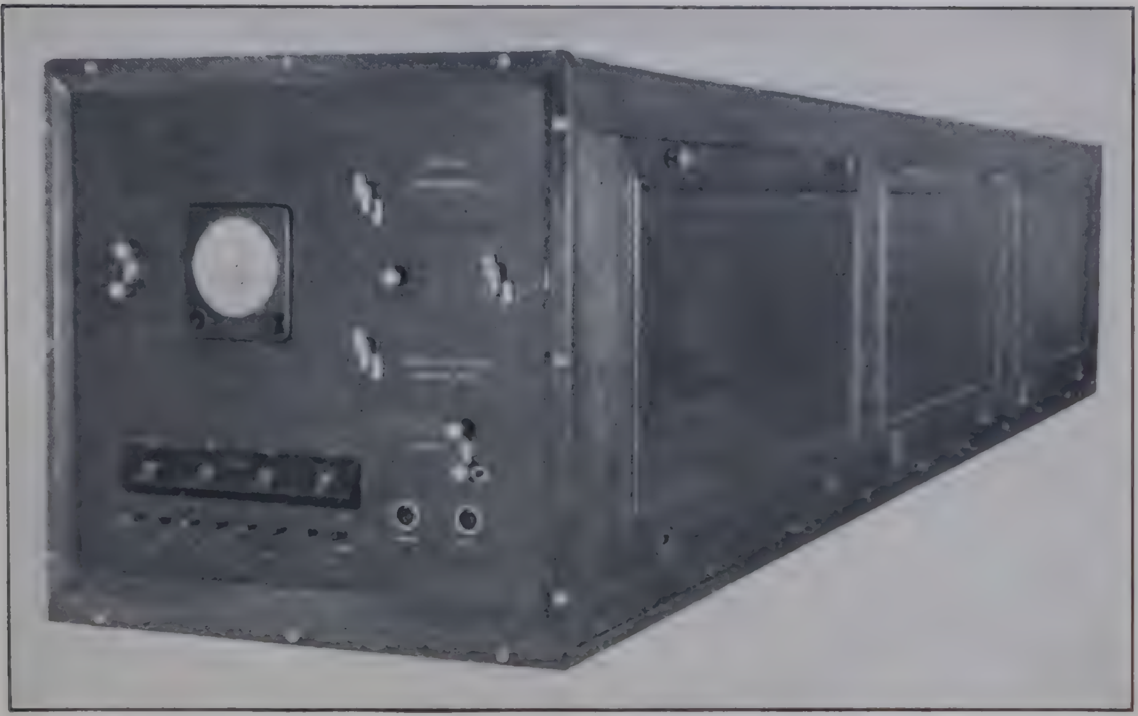


FIG. 3.13*b*. Grating spectrograph (concave grating in Eagle mounting) (Baird Associates).

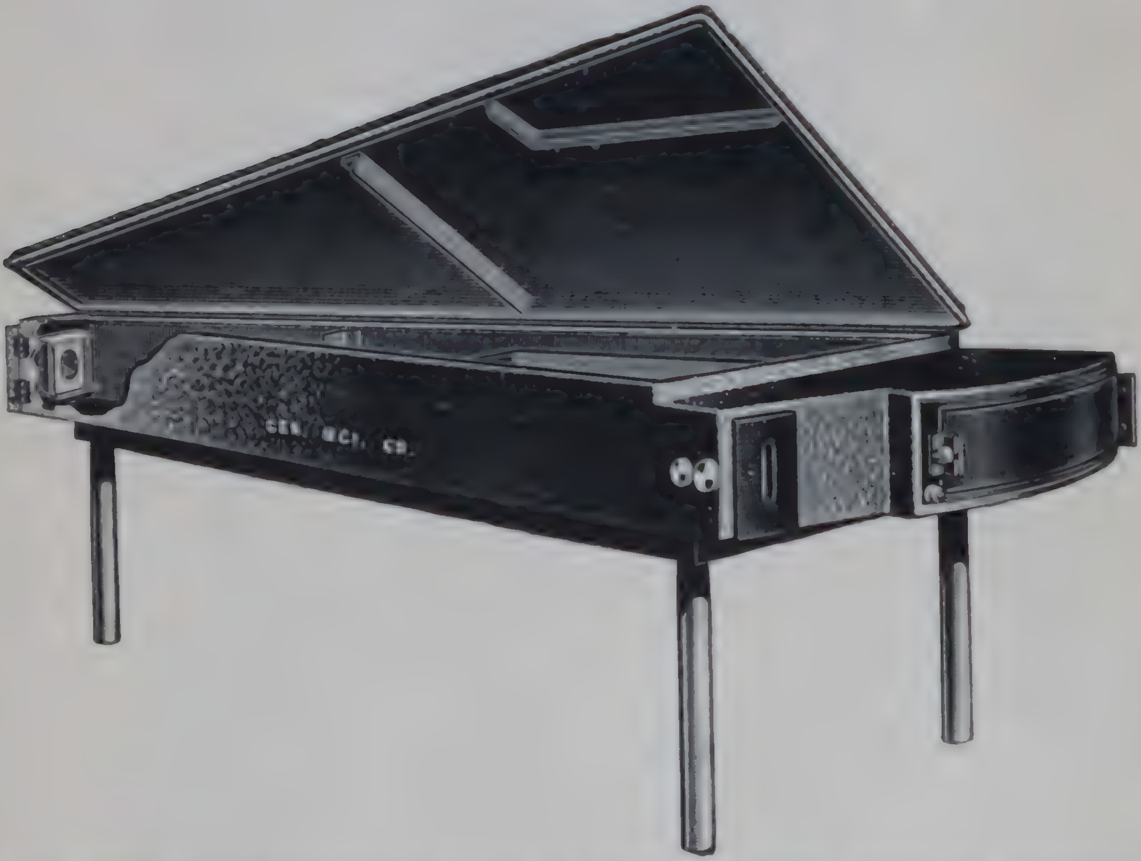


FIG. 3.13*c* Grating spectrograph (replica grating) (Central Scientific Company).

Efficiency of Spectrographic Equipment

The available supply of high-grade spectrographs and spectrographic equipment is limited owing to the exacting precision requirements in construction. In many spectrographic laboratories the initial cost of the instrument is offset by its long period of usefulness. It is often true that for some exacting spectroscopic studies an expensive instrument has in the end proved itself more economical than the lower-price instrument. On the other hand, there is a feeling in some laboratories that the best instrument for any particular purpose will be the most expensive. That this is not so can be seen by the comparison of the focal length and lens apertures of the small, medium, and large instruments of any manufacturer as compared with the price. It may be seen that the lens diameter of the 1.5-meter-focal-length Littrow instrument, which is a com-

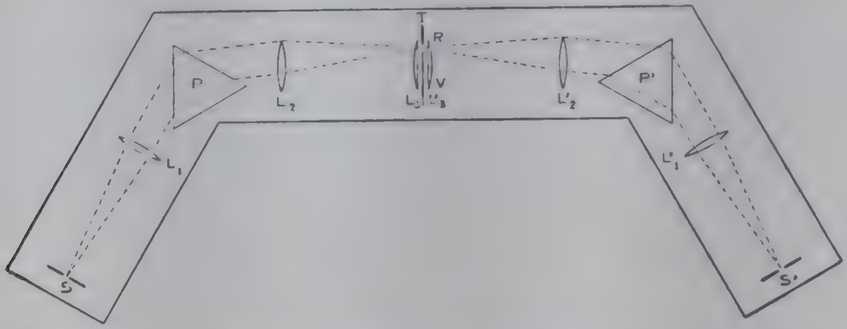


FIG. 3.14. van Cittert double-prism quartz monochromator (Kipp and Zonen).

FIG. 3.15. Monochromator (Bausch and Lomb).

mon size in many makers' instrument types, has a lens which is only slightly larger than the 75-cm Cornu type, which is also a very common size. The latter yields a complete spectrum on a 10-in. plate; the former requires four 10-in. plates. The Littrow instrument has a considerably greater dispersion and only a slightly greater resolving power. Its effective aperture, on the other hand, is smaller, and, for the examination of samples involving very minute traces of material, the smaller instrument of greater light-gathering power is to be preferred over the larger instrument of greater dispersion.

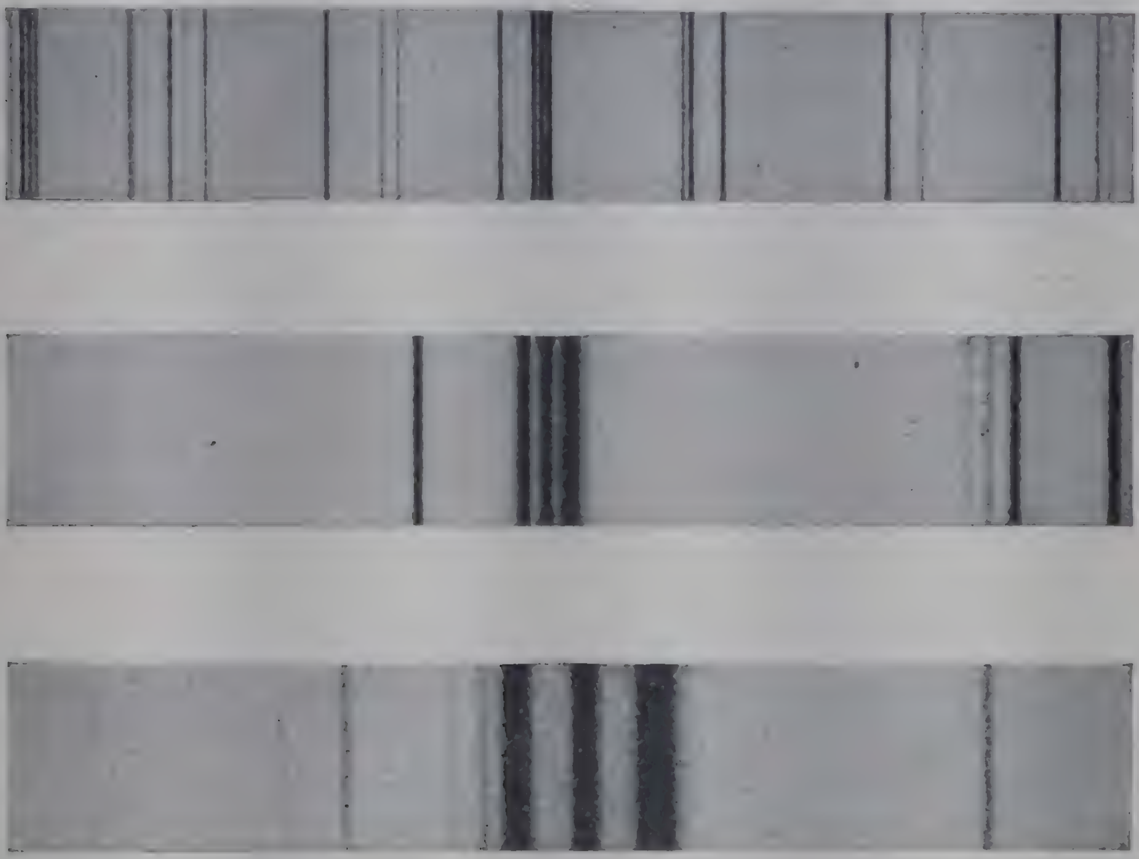


FIG. 3.16. Photograph from small, medium and large spectrograph, showing change in dispersion. N (iron triplet at 3100 A) (Hilger).

For absorption-spectra measurements on all types of solutions, the medium-sized (75-cm-focal-length spectrograph mentioned above) should be ample in size. For metallurgical studies on the elements of simple spectra, such as copper, brass, aluminum, zinc, and die-cast alloys, this instrument should also prove quite satisfactory. On the other hand, for studies of steel samples, for nickel, chromium, thorium, rare earths, and the like, a higher dispersion and resolution is almost necessary if one is to be able to separate the lines sufficiently for the identification and estimation of the amounts of impurities present.

The development of aluminized gratings for use as the dispersing element in spectrographs and, in particular, the improvement of coloring devices so as to concentrate the reflected light in a given spectral order have increased the efficiency of grating instruments to a point where they are equal and in some cases superior to the prism type. Grating instruments are available now in nearly the same sizes and dispersion units as have been available in the prism type of instruments.

DISPERSION (*D11*)

The efficiency of a spectrograph depends on a number of factors, chief among which is the dispersion and resolving power. The dispersion of any instrument of the spectrometric type is defined as the ratio of the change in the deviation of the light beam ($d\theta$) to the change in wavelength ($d\lambda$) and is expressed by the mathematical form ($d\theta/d\lambda$). Dispersion is dependent on the refracting angle and the composition of the prism. The composition of the prism, rock salt, glass, quartz, or other material, influences the bending of the beam on account of the variation of the refractive index of the material as compared with the refractive index of air. One may therefore express the dispersion of a prism as a function of the angular bending (θ) and the variation of the refractive index (n) with a change of wavelength (λ) in accordance with the following equation:

$$\frac{d\theta}{d\lambda} = \frac{\delta\theta}{\delta n} \cdot \frac{\delta n}{\delta\lambda} \tag{1}$$

The ratio of the change of deviation with a change of refractive index can be expressed for a 60° prism as

$$\frac{\delta\theta}{\delta n} = \frac{1}{\sqrt{1 - (n^2/4)}} \tag{2}$$

The remaining part of equation (1) can be determined from the Hartmann formula

$$\lambda = \lambda_0 + \frac{c}{(n - n_0)}$$

and can be expressed as

$$\frac{\delta n}{\delta\lambda} = -\frac{c}{(\lambda - \lambda_0)^2} \tag{3}$$

Substitution of equations (2) and (3) in equation (1) will give the expression

$$\frac{d\theta}{d\lambda} = \left(\frac{1}{\sqrt{1 - (n^2/4)}}\right)\left(-\frac{c}{(\lambda - \lambda_0)^2}\right) \tag{4}$$

The values of **c**, **λ**, **λ_0**, and n_0 can be determined if the refractive indices for three points are known. The final expression signifies a certain angular separation for any pair of lines of known wavelength separation and is independent of the size of the prism or spectrograph.

RESOLVING POWER

The resolving power of a spectroscopic instrument is the ratio between the average wavelength of a pair of lines that can just be separated, and the difference in wavelength between these two lines:

$$R = \frac{\lambda}{d\lambda}$$

For example, in an instrument which could just separate the two sodium lines in the D pair this expression would become

$$R = \frac{5893}{5896 - 5890} = 982$$

It can be shown that

$$R = t\left(\frac{\delta n}{\delta\lambda}\right)$$

where t is the base of the prism, and hence, where the refractive index-wavelength change remains fairly constant, as it does with most prisms, the resolution will depend on the prism size and will be independent of the focal length or magnification of the final negative. The practical resolving power of a spectroscope is always much less than the theoretical resolving power (R), which is dependent on lines and slits of extremely narrow finite width. In practice, the following relations hold with respect to the slit width, purity (practical resolving power), and intensity. The normal slit (slit factor = 1.0) is defined as the width for which the extreme difference from one edge of the slit to the nearest and farthest edges of the collimating lens is ($\lambda/8$), or as expressed in millimeters by multiplying by the factor $f\lambda/4D$, where f is the focal length in millimeters, λ the wavelength, and D the effective diameter of the lens. The normal slit gives a purity of spectrum (approach to theoretical resolving power) which is 1.4 per cent less than the maximum possible. If the slit factor is increased to 2.0, nearly double the amount of light is transmitted by the slit and the purity drops to 5.7 per cent below the maximum. A gain of three times the light means a loss of about 20 per cent of the purity, while a slit factor of 3.67 means a loss of half of the resolving power, and further increase in width decreases the purity of resolving power without much gain in intensity.

SLITS

Since in most instruments the photographic image in the spectrogram (spectrum photograph) is a replica of the slit, and in all instruments the spectral purity is a function of the slit characteristics, it is quite essential that the slit of the instrument be of exceptionally fine quality (*A23*). So far as the spectroscope or spectrograph is concerned, the slit is the light source from which the spectrum is obtained. An auxiliary light source from without is of course used to illuminate the slit, but the actual photograph obtained is a reproduction of the slit in each detail. If the slit has a slight indentation or projection caused by a nick in the jaw edge of the slit, or a dust particle, then each spectral line will show this as a wide or narrow difference in the spectral-line width, and in the entire spectrogram the dust particle will appear as a white streak on the negative, and the nick as a black streak. It is therefore quite essential that the slit be carefully cleaned to guard against the presence of dust particles between the jaws of the slit at the time of closing, and that extreme care be taken to prevent damage by closing the slit beyond the point of contact of the two edges.

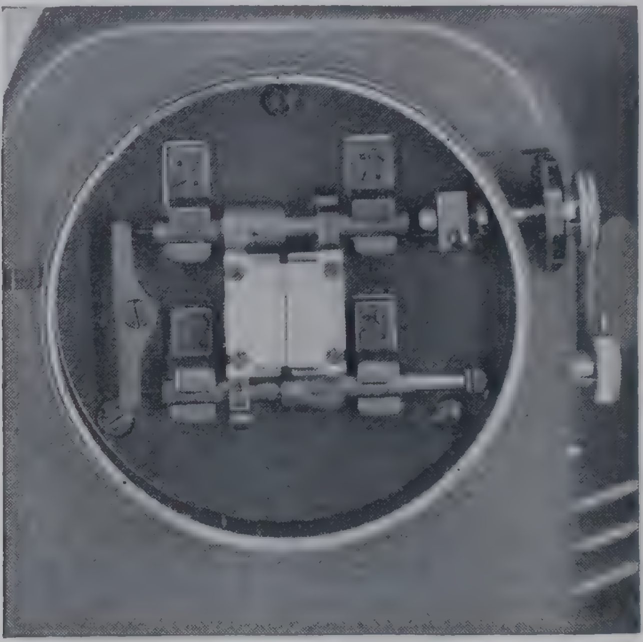


FIG. 3.17*a*. Bilateral slit mechanism (Bausch and Lomb).

In certain instruments the screw motion to open the slit is set to operate against a spring which normally holds the jaws together, and which is blocked at the point of contact so that it is impossible to damage the slit by turning the adjustment screw beyond the zero slit opening (Fig. 3.17*a*). In general, spectrographic slits are produced by cutting some non-corroding metal with bevel knife edges at 45° to the plane of the slit, the outer surface appearing as a single surface when the two jaws are in contact (Fig. 3.17*b*). On very accurate slits it is customary to bevel the outer surface also to a 45° angle so that the knife edge of the slit will be a 90° angle rather than a 45° angle. This adds considerable strength to the knife edge. This outer surface bevel is usually not greater than 0.3 mm.

Many instruments are supplied with bilateral slits, i.e., slits with jaws both of which move so as to maintain the center of the slit opening in constant position. Although theoretically this should be an improvement, there is little evidence to recommend the bilateral slit over the unilateral slit in small instruments (*A104*).

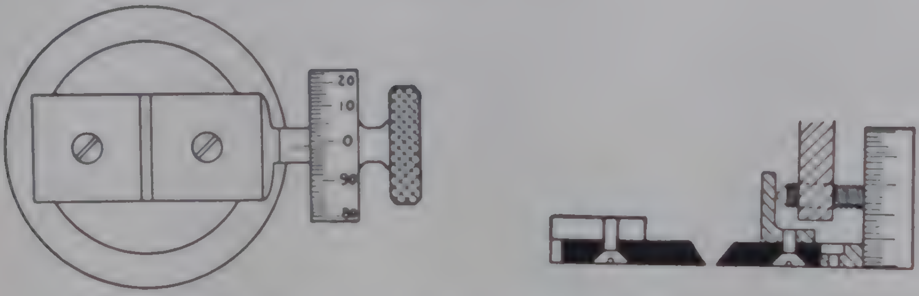


FIG. 3.17*b*. Diagram of unilateral spectroscope slit.

The width of the slit will determine to some degree the resolution and intensity of the line. It is obvious that a slit which is too wide will produce only a wider line without an increase in intensity. Schuster (*C180*) has developed a formula and table to indicate the relation between intensity and slit width. For the normal type of spectrograph which has an aperture of approximately *f* 1:10 the normal slit will be 0.005 mm at a wavelength of 546 mμ and a slit less than normal will cause no narrowing of the spectrum line. A slit width of four times this normal slit or 0.02 mm would correspond to a slit factor of four and produce a line which is over three times as intense as the normal slit line and nearly 80 per cent as intense as that theoretically produced by a slit of infinite width. It is obvious that to increase the slit width above this factor of four will cause only a slight increase in line intensity.

DIAPHRAGMS

Since, in all prism instruments and in certain optical modifications of the grating instruments, the spectrogram is a reproduction of the slit at different wavelength positions, the ideal place to introduce any diaphragms for superposition of one spectrum on top of another will be at the slit. Special diaphragms are available for the purpose (Fig. 3.18), by means of which one may vary the height of the spectrum on the plate, and thus by motion of the plate, in a direction at right angles to the spectrum, record a number of separate spectrograms on the same negative. With the Hartmann diaphragm which involves a number of openings in echelon it is possible to record several spectrograms on the same negative without moving the plate holder. This avoids any lateral shift of the spectrogram due to motion of the plate holder, or to an error in adjustment of the slit (e.g., if the slit is not parallel to the refracting edge of the prism, thus producing sloping lines in the spectrogram).

In some types of analysis (see discussion on quantitative analysis) it is desirable to have a series of photographs taken at different exposure periods. This can be approximated by the use of a step slit, in which the step edges of the slit act as diaphragms of different aperture (Fig. 3.19). Such a slit was designed by Hansen (*C95*) in 1924 and applied to a spectrograph, Duffendack (1934) (*C74*) has described this type of slit in a basic patent covering the principles of quantitative emission analysis.

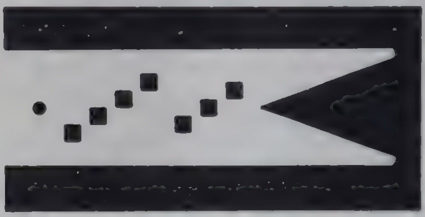


FIG. 3.18. Hartmann diaphragm.

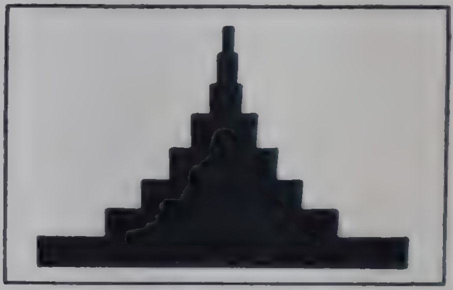


FIG. 3.19. Hansen step-slit.

A similar step slit for direct attachment on a spectrograph with slit steps of 0.02, 0.04, 0.08, 0.16, 0.32, 0.64, and 1.28 mm has been described by Scheffer in the catalogs of Franz Schmidt and Haensch (1912 and 1929). This type of slit (Fig. 7.12) enables the observer to compare a series of intensity measurements in a single photograph. The same effect can be obtained by placing a step sector in front of the slit, or by means of a graded density wedge such as can be produced by layers of evaporated aluminum of a varying thickness on quartz. It is to be noted that in the latter two methods the purity of the spectrum line remains constant, while in the step or wedge slit method there may be some error due to broadening of the line to include adjacent lines as well as a broadening rather than increase in density of the line after a certain density of image has been reached. In connection with the quartz plates with sputtered or evaporated density pattern it is of interest to call attention to quartz plates which have been silvered, and then a fine line of known width ruled or cut in the silver so as to produce a slit of known width. Such a slit can then be copper plated to yield a very practical slit of fixed width. Several such slits can be ruled on the same piece to provide a series of variable known slit widths. The slit on the Bausch and Lomb small Littrow spectrograph is an example of this. In large instruments this quartz plate may produce interference fringes on the lines, which can be partly eliminated by a sloping plate or a plate of a slightly wedge character.

As an alternative method to the Hartmann diaphragm for placing spectra in juxtaposition on the spectrum plate, some instruments are equipped with a diaphragm immediately in front of the plate holder so that spectra may be reproduced either partially superimposed or in juxtaposition by vertical movement of the diaphragm which can be adjusted in width. The movement of this diaphragm, like that of the Hartmann diaphragm, avoids the movement of the spectrum plate and insures exact alignment of spectrum lines in the two photographs. The use of this diaphragm adjacent to the plate is of particular advantage in the grating instrument where the astigmatic character prevents the use of a Hartmann diaphragm at the spectrum slit. A Hartmann diaphragm or step sector can be used with grating instruments provided that it is located at the focal point of the grating, which will be between the slit and the light source.

Another means of producing intensity gradient effects is the use of a filter in front of the photographic plate. It is difficult, of course, to get a uniform filter which will reduce all lines to the same degree, but this filter method has been advantageous where it is desired to reduce one line with respect to an adjacent line. In routine commercial analysis, one often wishes to compare the unknown impurity line against a line of the element that is present as a major constituent, which may be much more intense than the unknown line. A narrow filter step may be introduced in the instrument; it is often attached much like the scale printing devices so that it can be swung in and out of position. By the selection of a filter of proper density the unknown and control lines can be brought to nearly equal intensities for the medium of the range desired and hence the accuracy of observation considerably increased.

Another type of diaphragm involves the use of vertical slits adjacent to the plate holder. In this procedure, which has been developed for analysis of aluminum alloys, lines of the control (internal standard or aluminum), and certain unknowns such as Mg or Si are selected for analysis and a template is cut so as to transmit the selected lines through vertical slits which permit the passage of only a small amount of the spectrum on either side of the selected line. By the use of a horizontal plate motion which is equivalent to the width of the vertical slits on the template, a large number of separate samples can be photographed on a single spectrum strip, the number being determined by the distance between the selected lines and the width of the separate photographs as determined by the template opening. An additional advantage of this multiple-line photograph is that the plate can be placed in a recording microphotometer and the entire series recorded with the vertical plate motion.

The astigmatic character of the concave grating when used in Eagle, Paschen, and Roland mountings does not permit the use of a step sector, logarithmic sector, or Hartmann diaphragm at the slit. It can be corrected by means of a cylindrical lens between the slit and the grating (*C70*), or one can place these diaphragms or sectors at the vertical focus which is on the optical axis in front of the slit and whose position can be determined either by solution of a formula or experimental manipulation.

SCALES

Many fixed-position spectrographs are equipped with illuminated scales which can be printed on the negative above or below the spectrogram. In general, these scales are graduated in wavelength or frequency and in some cases with both units. Some fixed-position spectrographs as well as variable-position spectrographs such as the Littrow type are equipped with uniform division scales which can be used for reference. The variable-position instruments equipped with cam settings that can be reproduced permit the use of a graph for conversion of scale values to wavelength or frequency values. In addition to these scales which are printed directly on the spectrogram plate, some densitometers are equipped with a comparison beam (see Figs. 5.10 and 5.16) through which can be projected an image of a scale together with the indicated positions of the persistent lines of the elements. This is nearly equivalent to the projection of the spectrum upon a card upon which has been laid out a scale and the indicated positions of the stronger lines of the elements (see Plates II to XL in this book as well as those referred to in the list of tables on pages 620–658 in this book).

For the purpose of converting wavelength to frequency values, scale plates have been devised which permit the direct reading of frequency values from negatives with wavelength scales (see Fig. 7.62).

SOURCE AND POSITIONING LENSES

A source lens is generally placed between the source and slit so as to image the source on the slit. The imaging of the source on the slit permits the use of diaphragms to remove unwanted parts of the image such as the cathode layer or incandescent electrodes. The source lens should be of such size and focal length as to generate a cone of light the angle of which will be equivalent to or slightly greater than that of the cone generated by the collimating lens of the spectrograph with respect to the slit. The size of the desired image will determine in general the size of the source lens and its position on the optical bench. The use of lenses which generate large cones of light, such as short-focal-length lenses placed near the slit, though increasing the apparent intensity of the light on the slit, are of no advantage with respect to increasing light intensity on the recorded spectrogram since the slit beam will be diaphragmed by the collimating lens.

For purposes of alignment a light source may be placed at the long-wavelength end of the plate holder opening (*K*, Fig. 12.1) and the spectrograph adjusted so that the beam projected from the slit is parallel to the optical bench. The height and lateral position of the lens can then be set, only the horizontal or focus direction being left adjustable.

The position of the light source is thus determined by the source lens, and if the image is not properly centered the source and not the source lens should be adjusted in position.

For greater accuracy in placing of the source, especially when a long-focal-length lens is used adjacent to the slit, it is suggested that a test screen and lens be provided (see Fig. 3.3). The screen can be graduated so as to permit accurate positioning of the source as well as a determination of the spacing between electrodes.

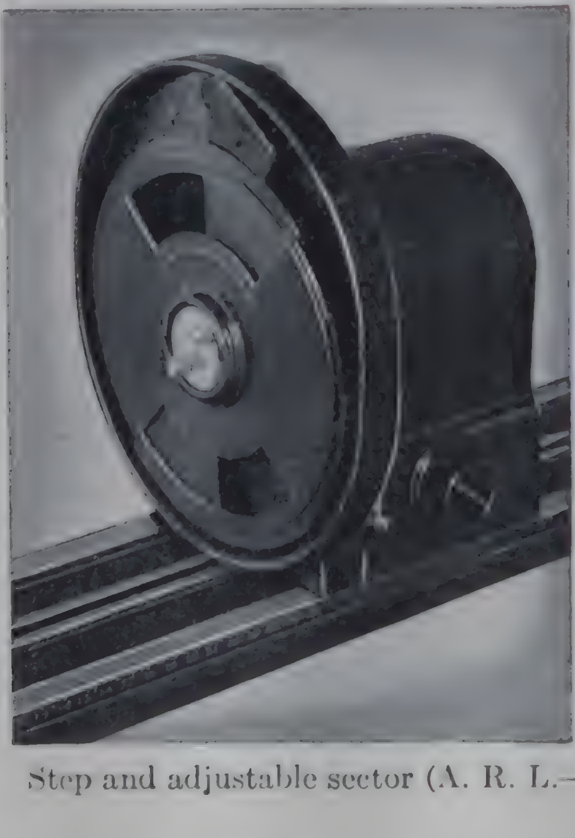


FIG. 3.29. Step and adjustable sector (A. R. L.—Dietert).

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Two modifications of the source lens system are cylindrical or spherocylindrical lenses and long-focus spherical lenses. Cylindrical or spherocylindrical lenses are commonly placed with the cylinder axis vertical so as to focus a line of light rather than a point of light at the slit. Cylindrical lenses provide a uniform slit illumination such as is necessary for sector or diaphragm exposures at the slit. Placing the cylindrical lens in a horizontal position permits a wide horizontal motion of the light source without the image leaving the slit.

Long-focus lenses are often employed to provide uniform illumination at the slit for use with logarithmic or step sectors. Such lenses should be placed adjacent to the slit (see Fig. 12.16) generating a cone of light so as to focus the image of the source on the collimating lens. Suitable diaphragms may be placed at the collimating lens to remove unwanted portions of the spectrum. A test lens and screen are essential in this latter type of illumination since the long focal length of the source lens will make the source position critical with respect to its image position at the collimating lens.

Diaphragms at the source or collimator lens reduce the light intensity, permitting longer exposures and better sampling. Other devices for reducing light intensity include rotating sectors of variable opening in the light path (Fig. 3.20).

Shutter Mechanism

In the preliminary adjustment of the light source it is desirable to be able to focus on the slit and observe the arc position in relation to the slit opening, before any exposure has been made. For this reason it is essential that the instrument be equipped with a shutter mechanism between the slit and the plate. (The use of the dark slide of the plate holder for this purpose is unsatisfactory in that it requires considerable manipulation and may result in a lateral motion of the plate between spectrum photographs.)

Light Sources

Atoms and molecules are excited by application of energy in the form of heat or electricity. Low-temperature excitation is best obtained by a flame, producing temperatures from 1000 to 3000° C. For higher temperatures electric arcs may be used, in which temperatures from 3000 to 6000° C may be obtained, and for still higher temperatures a spark source may be used. For gaseous materials an electric discharge (Geissler tube) forms the most convenient means of excitation.

Flame Sources. Except for the alkali metals the flame source is not a very satisfactory method of atomic excitation. The qualitative flame testing of unknowns is important, however, and the test for potassium in the presence of sodium by the use of a dark purple glass is essentially a spectrometric examination in which the colored glass acts as the dispersion instrument. To avoid a continuous background one needs a nearly colorless flame into which the sample may be introduced, either externally, by means of a platinum wire, asbestos-soaked piece, or spray; or internally, by means of an atomizer system in the gas or air line so as to pass a spray into the flame, or volatile compounds of the element to be tested (Fig. 3.21). The determination of boron by means of methyl borate is an example of this last method, namely, the introduction of a volatile compound into the flame.

The disadvantage of a flame source lies in its relatively low temperature, and hence its ability to excite only the alkali metals and the lower states of the alkaline earths and a few other elements. Only twenty-five elements emit spectra in flame excitation, and their sensitivity is comparatively low in most cases. This disadvantage becomes an advantage where it is desired to detect these substances in the presence of a large amount of material of higher excitation potential. With the alkaline earths and a large number of other substances, the spectra produced will consist largely of diatomic or molecular band spectra rather than the atomic line spectra. Copper, in itself, does not color the ordinary flame, but the halogen salts of copper impart a brilliant green to the flame color with the production of a band spectrum of the corresponding copper halide. At ordinary flame temperatures the red color produced on the heating of strontium nitrate is not due so much to excited strontium as to the band spectrum of strontium oxide, and the same is true for the calcium and barium flame colors. The flame tests are usually made with the halides, owing to the lower volatility and excitation potentials of these salts, and identification is often made from a band spectrum rather than a line spectrum. The flame tests may also be utilized to identify certain anions such as the halogens, which can be identified only with great difficulty by the higher excitation methods of atomic spectra.

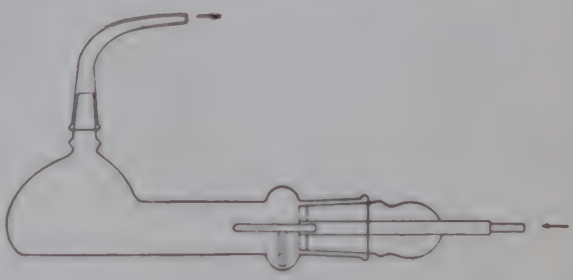

FIG. 3.21. Lundegardh atomizer for flame spectra of salt solutions (*A68*).

In the method of flame analysis developed by Lundegardh an acetylene flame has been used, and satisfactory determinations have been made on some thirty-two elements, including Ag, Au, Ba, Ca, Cd, Co, Cr, Cs, Cu, Dy, Fe, Ga, Gd, Hg, In, K, La, Li, Mg, Mn, Na, Nd, Pr, Ni, Pd, Rb, Rh, Ru, Sr, Tl, Y, Zn. The most sensitive lines for flame analysis of these elements have been indicated by the letter "F" in Table VI. (*A68*.)

Arc Sources. Probably the most widely used and most satisfactory method of atomic excitation is the electric arc. Temperatures in the electric arc range from 1000 to 6000° C, depending on the current density and electrode size (Fig. 3.22). The electric arc is a polarized source (*C155*), and hence one would expect a high concentration of negatively charged particles in the neighborhood of the positive pole and of positively charged ones in the neighborhood of the negative pole. In spite of the application of current ranging from 150 to 250 volts the actual voltage drop between the electrodes is only about 40 volts, and most of this drop occurs adjacent to the cathode electrode where lines of higher ionization states are produced. Lines caused by impurities are enhanced in this cathode layer, and a method of analysis by a study of the cathode layer spectra has been devised (*A89*). Some metals, such as iron, tend to form a bead of oxide at the positive pole, and so the anode should be the lower electrode in the direct-current arc. For other metals the polarity may not be of great importance, and either polarity may be used for the bottom electrode.

For most spectroscopic determinations it is desirable not to use the entire arc as a source but rather to focus on the center of the arc, so as to avoid the ionic concentrations at the poles and the continuous spectrum produced by the incandescent pole pieces.

From examination of the voltage drop which occurs across the arc, it is obvious that there is a cathode layer adjacent to the electrode in which the nature of the voltage drop would produce lines of different character from those produced in the remainder of the arc. For this reason it is customary to use the center portion of the arc flame, which is more homogeneous in character. There may be cases, however, where the excitation produced in the cathode layer is essential for the elemental detection or estimation. In most descriptions of apparatus an arc of 100 to 200 volts is indicated. It should be pointed out, however, that in actual practice such arcs are uncommon since a ballast and resistance are used in the circuit and although the supply may be from 100 to 200 volts the resistance of the arc itself means that usually the voltage drop across the arc will be between 50 and 60 volts with a current density of 3 to 6 amperes. (See Fig. 3.25.)

With two carbon electrodes, it is customary to place the sample in the anode (positive electrode), which serves as the lower electrode. D. M. Smith (*A85*) has pointed out that, if the known metal is to be one electrode and the second electrode is to be either carbon or a pure metal, the unknown electrode under investigation should be the cathode.

For simple spectrum photographs the use of a definite portion of the arc image can be accomplished by focusing the entire image of the arc on the spectrum slit, so that the image is about two to three times the length of the desired slit height, and inserting a wedge or Hartmann diaphragm in front of the slit to cut off the unwanted portions of the arc image. For purposes of alignment in both arc and spark apparatus it is advisable to have an optical bench with fixed electrode positions, and a secondary lens system (L_4) to focus the source on a test screen (Fig. 3.3). The purpose of the secondary lens and screen is to permit a rapid adjustment and alignment of the arc or spark source, since the optical path of the spectrograph and light source may be set in line with the secondary lens and screen. Numerous types of arc and spark holders are available on the market, among which there is little difference in regard to method of use (Figs. 3.4*a*, 3.9, and 3.23). Most arc holders are sufficiently well insulated thermally and electrically to be used for either arc or spark determinations. The ideal arc holder should be independently adjustable in a direction parallel with the slit and perpendicular to the optical path, and perpendicular to the slit and perpendicular to the optical path. It should be adjustable in a direction parallel with the optical path, although this is not essential, and any such desired adjustment could be made by a change in the focal position of the lens (L_1). For the production of a mixed spectrum from two different materials, such as nickel and iron, it is essential to set the electrodes in a horizontal position (perpendicular to the slit) rather than parallel with the slit. Such an adjustment is provided in the arc holder illustrated in Fig. 3.23. The arc

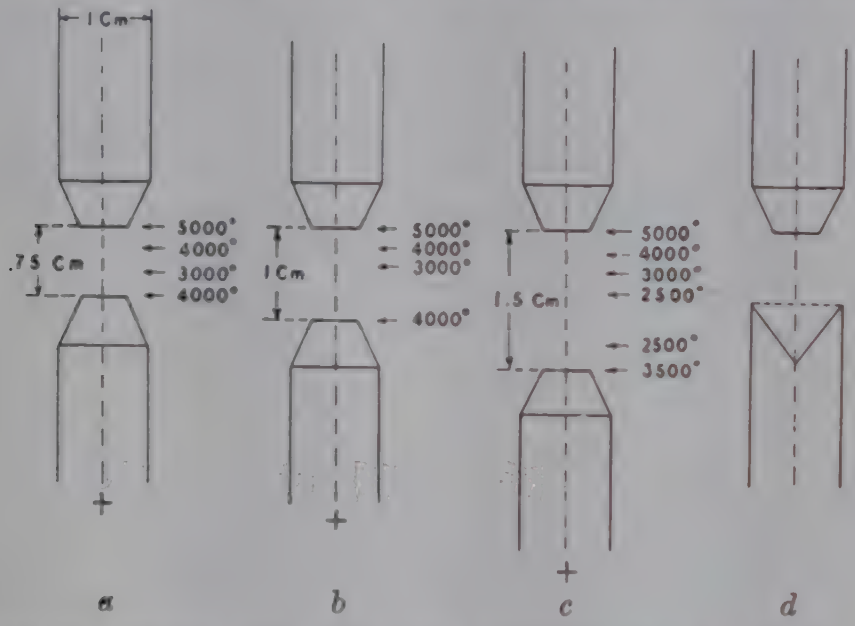

FIG. 3.22. Relation between gap length and temperatures in a carbon arc (*a*, *b*, *c*). Cupped carbon for analysis sample (*d*).

holders should be capable of taking ¼- to ⅜-inch rods directly, as well a smaller rods or wires, and, in addition, spring clips should be available fo these holders so as to permit the use of small or irregularly shaped samples

Carbon Electrodes. For nonmetallic-nonconducting samples it is necessary to have a conducting electrode such as carbon and to introduce th sample in small pieces or powder form into a cored portion of the lowe (positive) electrode. For such analyses the carbon electrode need not b over an inch long, and the cored recess, which can be produced by machine drill, should be about 4 or 5 mm deep (Fig. 3.22*d*). It is recommended that solid electrodes greater than ¼ inch should not be used f arc measurements unless a high current density is also essential. Goo carbon electrodes, free from nearly all impurity elements, can be obtain from the National Carbon Company. These are known as spectroscop carbons. A still purer carbon electrode can be obtained from the Nation Carbon Company, from the Dow Chemical Company, or from th

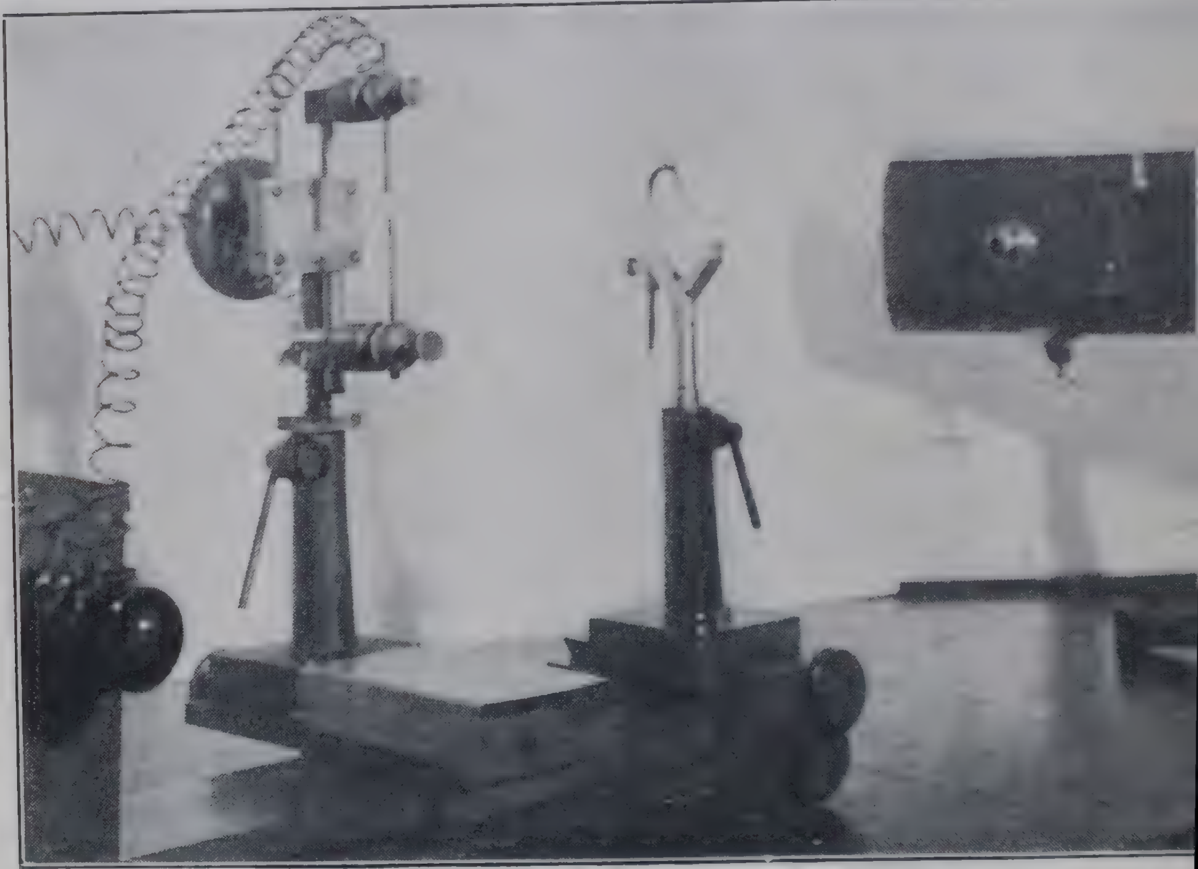

FIG. 3.23. Arc and spark electrode holder on optical bench. Arc holder has bee reversed on optical bench to show construction. Both lens holder and arc holder hav a similar base with a locking screw to clamp to optical bench (lower disk) and a sid wise motion screw (upper disk). Arc holder has a vertical-motion ring adjustme (above locking lever). The threaded shaft has a keyed slot to keep arc in alignmen An insulated knob operates a rack-and-pinion adjustment of arc or spark widt Electrode clamps are insulated for spark use and constructed with cooling fins for a use. Material may be used in rod form or held by spring clips.

Speer Company. These high-purity carbon electrodes are free from even spectroscopic traces of most impurity elements. This extra degree of purification increases the cost of the electrode (1 inch by ¼ inch) from about one cent to about ten cents (assuming that a number of 12-inch rods are purchased by the user at one time and cut to the inch size), but it is often worth the added cost when the elements under investigation may be impurity elements in the spectroscopic carbons. For many purposes, however, the lower-priced electrodes will be found to be quite satisfactory.

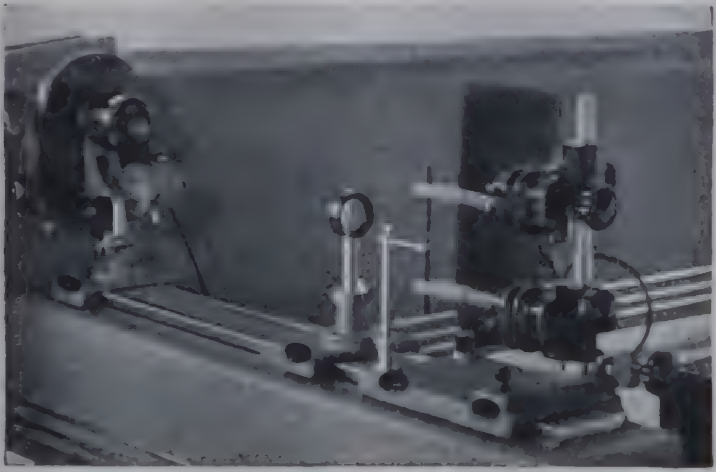

FIG. 3.24. Arc-spark source on optical bench (Bausch and Lomb).

In the analysis of powdered material, both conducting and nonconducting, it has been found highly satisfactory to briquette the material under high pressure so as to produce a small, solid pellet which can be introduced into the carbon or metal electrode. The use of finely powdered material permits the incorporation of an internal standard with the solid matter. Another procedure which has been proposed (*A89*) involves the incorporation of the sample with powdered carbon (the carbon obtained from coring the electrode is very satisfactory for this purpose), and on some occasions this is incorporated with lithium carbonate so as to produce a smoother and freer-burning arc as well as to dilute the sample and thus permit longer exposure, in which current characteristics and focus can be more easily controlled.

Arc Spectra of Solutions. Special technique may be necessary in the examination of the arc or spark spectrum of solutions. In the examination of solutions, it has been suggested that the solution be allowed to drop slowly into a cored receptacle of a hot (about 105° C) electrode (*C170*). After evaporation the electrode may be arcked in the usual manner. If there seems to be a tendency for the liquid to diffuse through the electrode instead of evaporating in the cup, a drop of kerosene may be introduced into the cup or the electrode end may be dipped into molten carnauba wax and the electrode heated so as to allow the wax to penetrate. This oil or wax treatment reduces the penetration into the electrodes of the aqueous solutions during their evaporation.

Electrical Circuit. The electrical circuit for an arc source is indicated in Fig. 3.25. It is assumed that a d-c supply of at least 110 volts is available, and a higher voltage is often of some advantage since it will permit an easier control. The electrical circuit should have an ammeter in series with the supply, and a voltmeter attached to the leads to the electrodes so as to record the voltage drop across the electrodes. A resistance (*R*) and inductance (*L*) should be included in the circuit. The resistance should be of an adjustable slide-wire type and capable of carrying a load of 10 amperes at 12 ohms resistance. The inductance will steady the arc and maintain a more constant voltage. For most current supply, the primary of a 1-kva transformer will act as a very satisfactory inductance.

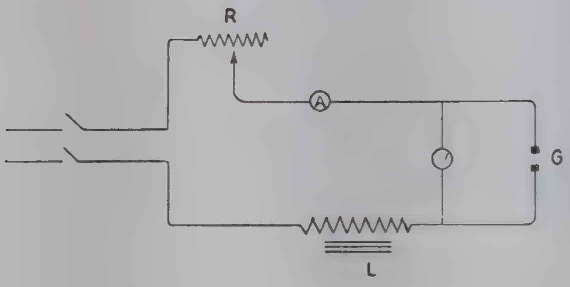

Fig. 3.25. Electrical circuit for an arc source.

Fig. 3.26. Rectifier for arc source, converts 115-volt alternating current to 60-volt 5-ampere direct current (Raytheon Manufacturing Company).

In laboratories where direct current is not available through a battery, converter, or power supply, or where the arc would prove too much of a drain on the battery system, it is suggested that a portable rectifier (Fig. 3.26) be used. This special type of rectifier is designed for supplying current to a ¼-inch electrode arc and is built with a current-limiting transformer so that an external ballast or inductance is not necessary. The model illustrated supplies 5 amperes at 60 volts direct current and operates from 115 volts alternating current. (See also Fig. 3.27.).

The Pfund (*C160a*) arc is a special type designed to yield a steady high-intensity light source and is generally used for the production of standard iron spectra. The cathode, placed above, consists of a 6- to 7-mm rod of iron, having near the arc end a large block of copper or brass to act as a cooling device. The anode, placed below, consists of a bead of iron oxide on the end of a heavy iron rod. The current should not be over 5 amperes (the initial line voltage being 110-250 volts) and the arc should have a gap of about 12 to 15 mm.

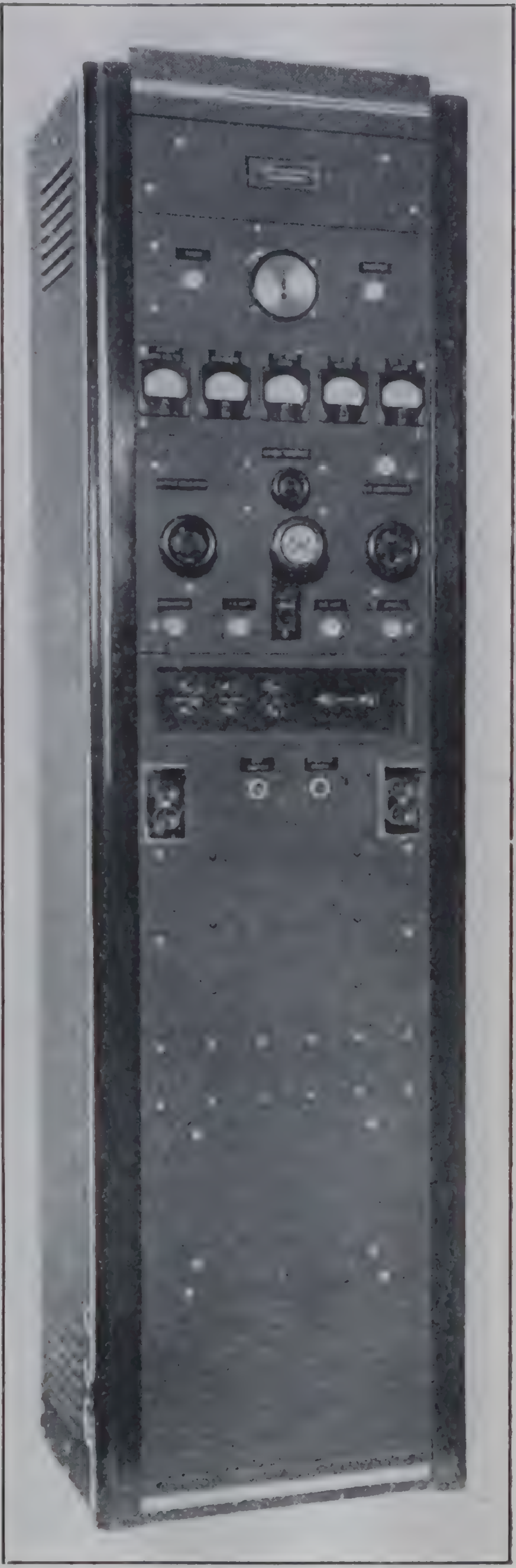

FIG. 3.27. Combination a-c arc, a-c spark, and d-c arc source unit (Baird Associates).

Duffendack, Owens, Wolfe, and others have suggested the use of a high-voltage alternating current arc for spectroscopic illumination (*C26*) and have claimed many advantages in reduction of background, low heating effect of electrodes, and small sample requirements, as well as certain excitation advantages resulting from the higher voltage. This high-frequency a-c arc actually has a potential drop of only about 50 volts, whereas in the d-c arc voltage drop occurs for the most part adjacent to the electrodes (Fig. 3.28). The use of this high-voltage (2200 volts) a-c arc involves some possible experimental hazard, and it is not advised for classroom work. For industrial or routine analysis by competent observers there should be no great danger if proper precautions are maintained. The arc holder itself (Fig. 3.29) has been designed for rapid analysis procedure with electrodes of uniform length which are inserted into the lower electrode so that the height of the electrode will always be at the center of the optical path. The top electrode is held

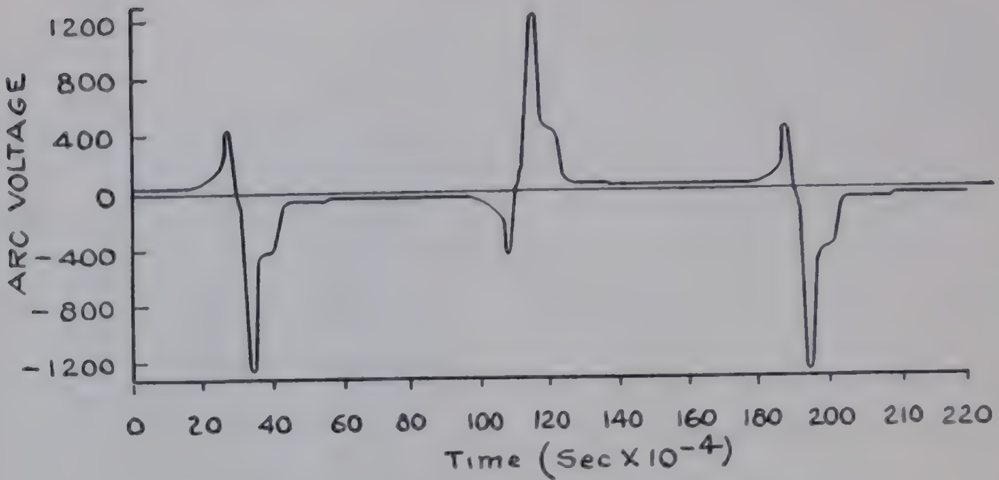

FIG. 3.28. Voltage-time pattern of a-c arc. (*C26*).

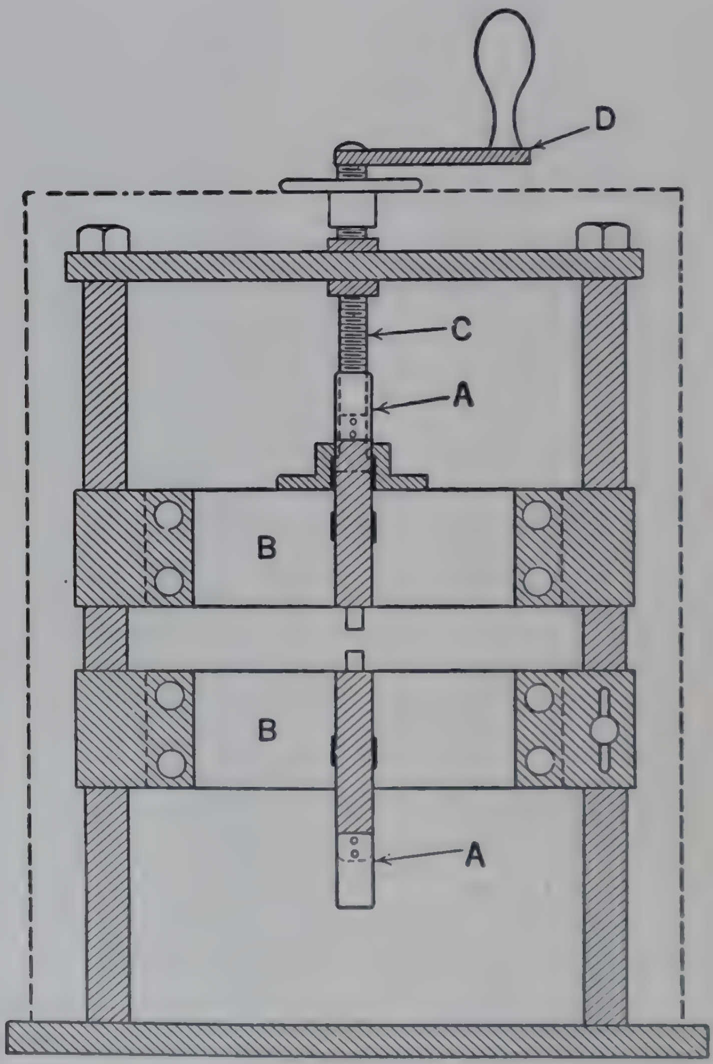

FIG. 3.29. High voltage a-c arc holder. *A*, *A* are spring clamps for holding th electrodes; *B*, *B* are Bakelite insulators; and *C* is a screw of 0.5-mm pitch which ma be turned by the insulated handle, *D*. The lower electrode can be adjusted in positio by sliding it on the uprights, and the upper electrode is set by means of the screw The arc stand is enclosed in a cage to protect the operator from the 2200-volt circu which maintains the arc. (Duffendack and Wolfe [*C75*].)

in a screw and friction clamp so that it may be screwed down to contact with the lower electrode by means of the insulated handle. Continued screwing down on the handle will merely cause the electrode to slide in the friction part of its holder, but on reversal of the screw motion the electrodes will immediately start to separate. Since the pitch of the screw is in millimeters, it is possible to screw the electrode down to the sample electrode and continue until the handle reaches a given mark and then, reversing the direction to one half or one revolution, thus to produce a gap of ½ or 1 mm. Although in normal arc sources the gap will be from 5 to 10 mm or even greater this type of a-c arc will be found to operate best at a gap width of ½ to 1½ mm.

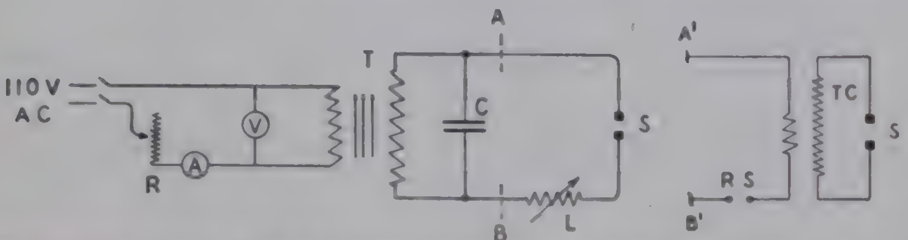

FIG. 3.30. Electrical circuit for a spark source. Tesla spark indicated in A'—B' circuit.

The a-c arc produces a high-voltage discharge on the first cycle of oscillation which is followed by a more uniform oscillatory discharge of lower voltage. In this second portion of the discharge, the voltage seldom rises over 150 volts.

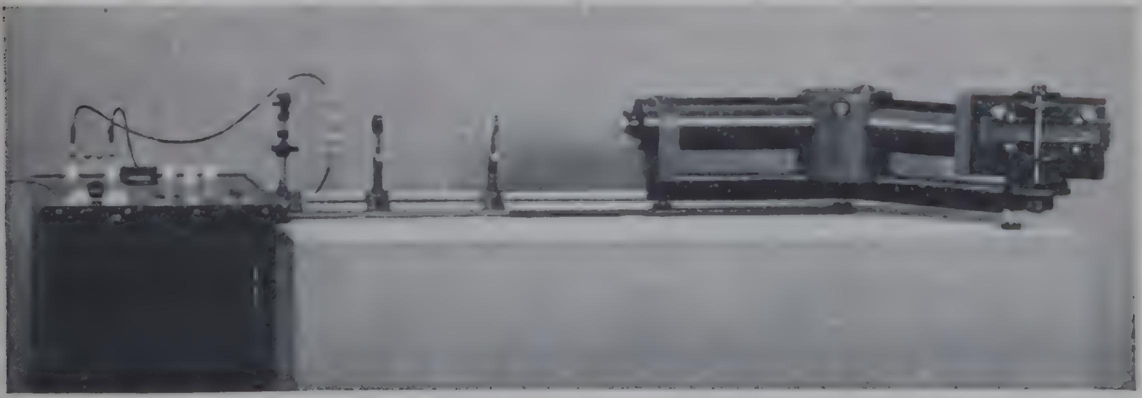

FIG. 3.31. Spectrographic arrangement for spark analysis, showing spark generator, spark-holder stand, condensing lenses, and medium spectrograph (Zeiss).

Spark Sources. The nature of the electric spark is largely determined by the resonance system which can be set up between the condenser and inductance circuits, the usual source being that indicated in the diagram (Fig. 3.30), in which the capacity of the condenser (C) and the inductance of the coil (L) can be adjusted to yield the proper wave form or resonance to the spark (Fig. 3.31). The variation of the spark conditions will yield what is known as a condensed or uncondensed spark, the two types being quite different in the intensities of spectral lines produced. The electrodes for spark analysis should, if possible, be pointed so as to keep the spark from wandering out of the optical path, and the gap should be from 3 t 6 mm in length, depending on the circuit conditions and the size o image desired on the spectrum slit.

The condensed spark will be more intense than the uncondense spark but will also have a great many more air lines, due to nitroge and oxygen. The self-inductance in the secondary circuit will materiall reduce the intensity of these air lines. The self-inductance is an open coi with adjustable taps to provide for various induction valves. The actio

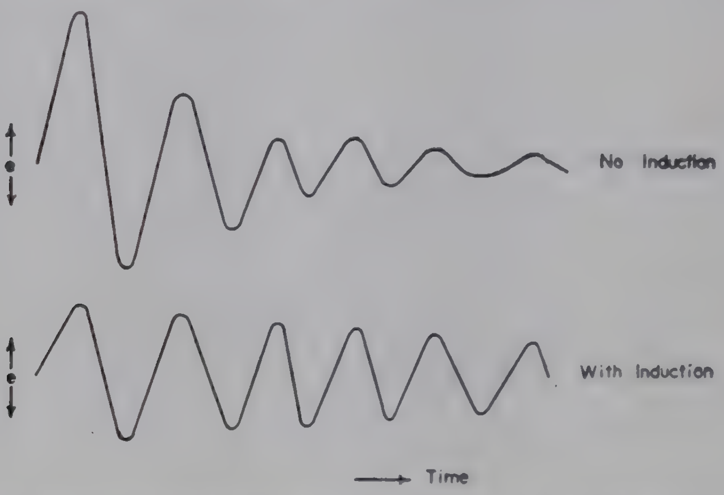

FIG. 3.32. Oscillatory nature of a spark discharge (*a*) without induction and (*b*) wit induction.

of the self-inductance, like that of the arc circuit, is to prevent sparkin at the first surge of current and maintain the spark as the current drop so as to provide a steadier and more uniform spark (Fig. 3.32). The self-inductance will reduce to a slight extent the intensity of light emitte but will set up a more uniform oscillating system. The frequency of thi oscillating spark may be expressed as

$$n = \frac{1}{2\pi\sqrt{LC}}$$

where n = oscillations per second; L, the self-inductance in henrys; an C, the capacity in microfarads. For a spark using a secondary voltag of 10,000 to 15,000 volts, a capacitance of 0.001 to 0.005 microfarads an inductance with a range of 0.02 to 1.5 millihenrys will be quite satisfactory. The self-inductance may easily be constructed as an open co wound on a glass or insulating cylinder about 4 to 5 cm in diameter an with 50 to 100 turns spaced about 2 mm apart.

In order to utilize definite portions of the spark phase it is often customary to incorporate in the circuit a synchronous interrupter in series with the resistance at *A* (see Fig. 3.30). By adjusting the phase angle of the synchronous interrupter it is possible to select a definite portion of the spark phase for discharge through the light-source gap (*C113*).

The Feussner spark operates so as to use only the first or first few oscillations of the spark, the remainder of the spark being interrupted by a rotary interrupter or by a dampening effect in the circuit to absorb subsequent oscillations.

Synchronous sparks are obtainable by means of a mechanical (synchronous motor) interrupter (Feussner spark) or an electronic interrupter for the production of condensed spark discharges (*C160, C129*) (Fig. 3.33).

In both types of interrupted spark sources as well as a-c arc sources care should be taken that step or logarithmic sectors in the optical path are not synchronized with the emission source (Fig. 3.34).

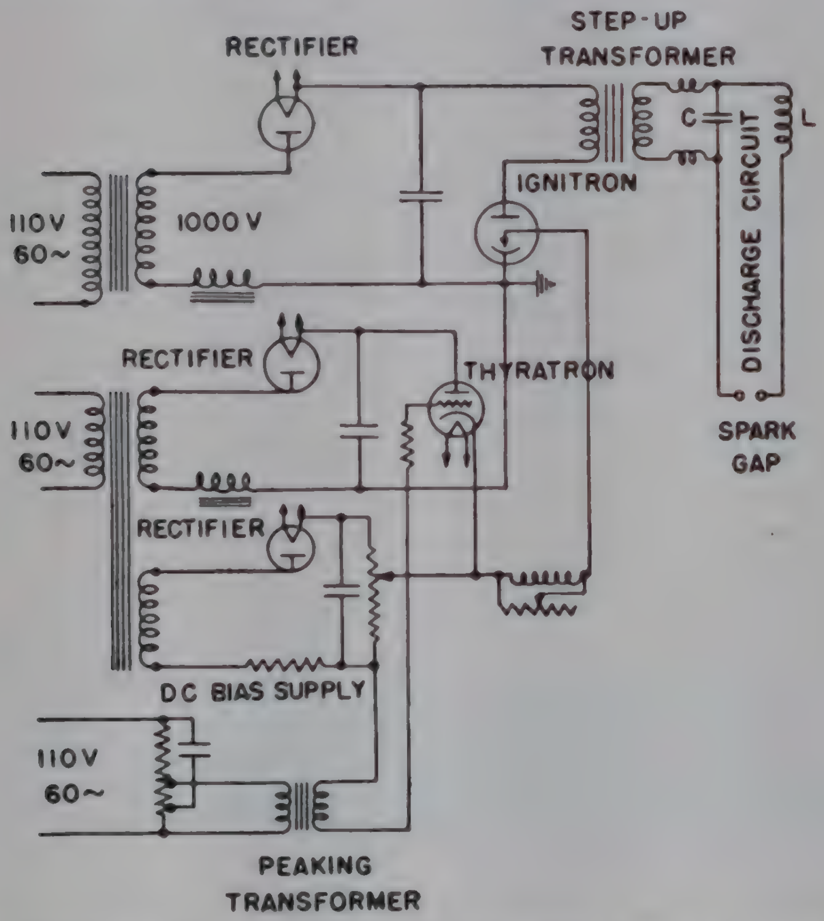

Fig. 3.33. Electronic circuit for producing condensed spark discharges for spectrographic analysis (Malpica and Berry) (*C129*).

Comparison of Arc and Spark Sources. It is difficult to say which method of excitation is to be preferred, the arc or the spark, the choice being largely dependent on the available power supply, the character and the amount of the sample, and the type of lines which are desired. For low-melting substances, such as lead and tin alloys, Wood's metal, and similar products, the spark is to be preferred on account of the temperature conditions of the arc. The spark really involves a much higher atomic temperature than the arc, but a lower electrode temperature. For such low-melting substances an arc method is satisfactory, but it may require intermittent exposures with cooling of the electrode or the use of a carbon arc to hold the low-melting material while arcking. The spark is relatively free from the continuous background found in the carbon arc (CN bands) between 3200 and 4200 A (Fig. 3.35). The spark is better suited to the analysis of a minute amount of material or to the analysis of a spot on a larger metallic surface without disturbing the remaining surface. On the other hand, the arc is usually better suited where a large amount of material is available but the concentration of the element sought is low. In other words, it is more difficult to burn up or sample an electrode by the spark method. Solutions lend themselves more readily to direct spark analysis since the electrode temperature is relatively low. The solution may be introduced directly into the spark through a separate tube (Fig. 3.36), it may be sprayed into the spark,

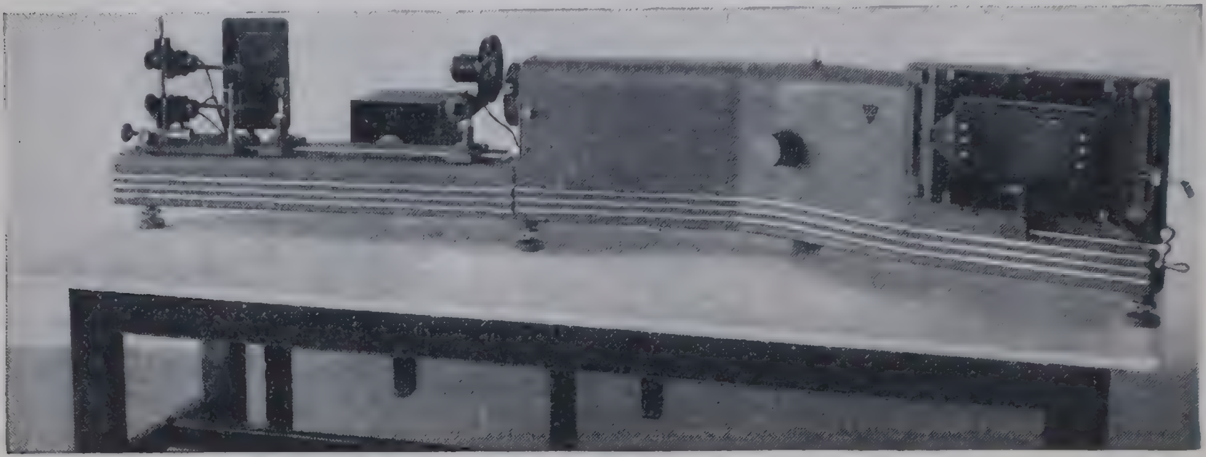

FIG. 3.34. Arc-spark source unit with variable speed adjustable sector (Bausch and Lomb).

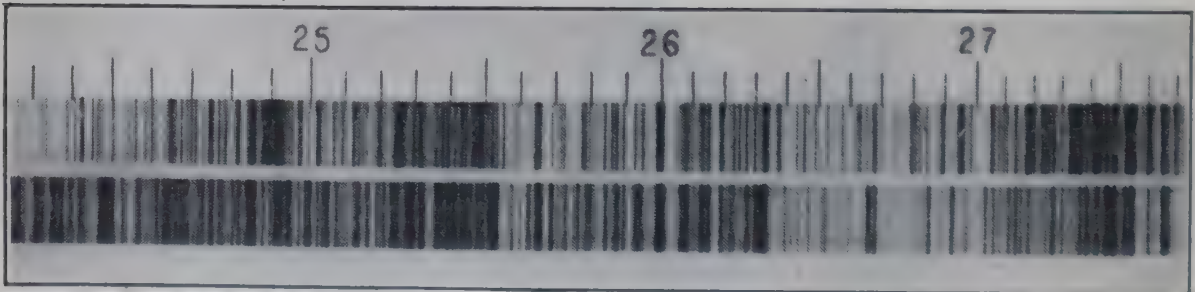

FIG. 3.35. Comparison of arc (upper) and spark (lower) spectra of iron N.

or it may involve the use of the solution, if an electrolyte, as one of the electrodes. Then carbon, gold, or some inert metal with a relatively small number of lines may serve as the other electrode.

A laboratory equipped for spectrum analysis should have available both arc and spark methods so that one method can supplement the other.

Gaseous Discharge Source (*Geissler Tube*). For the detection of the rare gases, He, A, Kr, Ne, Xe, as well as H, O, N, S, and certain molecular combinations, it is desirable to have available a discharge tube which can be filled with a gas at a low pressure. At low pressures, gases may be excited either by electrode or electrodeless discharge of a high-voltage current (a 30-milliampere 5000-volt neon sign transformer is ideal for this purpose) to produce a characteristic high-voltage spark spectrum. In view of the fact that the intensity characteristics of the spectrum are markedly influenced by the excitation potentials of the elements present, it is difficult to apply quantitative or even qualitative analysis methods to gases. For example, mercury, with a low excitation potential, will transmit practically all the energy in a tube containing neon and mercury, so that it is difficult to show the presence of neon, which has a very high excitation potential.

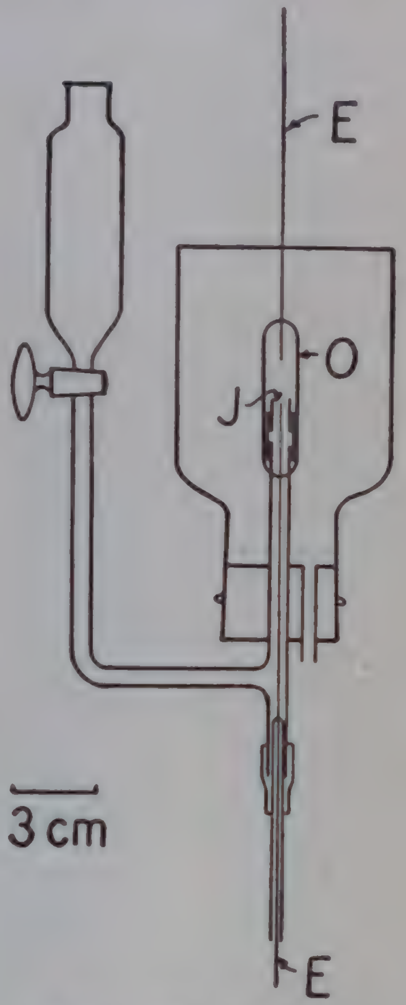

FIG. 3.36. Spark arrangement for solutions showing electrodes, *E*; illumination opening in glass shield, *O*; and quartz jet, *J* (adapted from Twyman and Hitchen) (*C195*, *C52*).

For purposes of spectroscopic calibration and for standard reference lines, mercury, sodium, and neon tubes form convenient light sources. These lamps are available in glass or quartz, depending on the spectral range desired and element contained. In recent years a number of these discharge lamps of a low-voltage, self-starting type have been developed (Fig. 3.41) which are very convenient as permanent laboratory standard lamps for the recording on the spectrogram of calibration lines much as the iron arc is used. In the red portion of the visible spectrum the number of iron lines is limited and the accepted secondary standards in this region include a number of neon lines. It is possible to fit adjacent to the slit of the spectrograph a small right-angle prism, covering only a portion of the slit, or fitted to swing into position when desired, so as to record from a permanent discharge tube attachment the comparison spectra without disturbing the equipment in the direct optical path of the spectrograph or spectroscope. With mercury discharge tubes (Figs. 3.38 and 3.41) one may interpose special filters to absorb the radiation from all the lines except one and thus produce a very good monochromatic light source (Fig. 3.40). Having a set of these filters, one may dispense with a spectrometer in making a series of spectrophotometric measure-

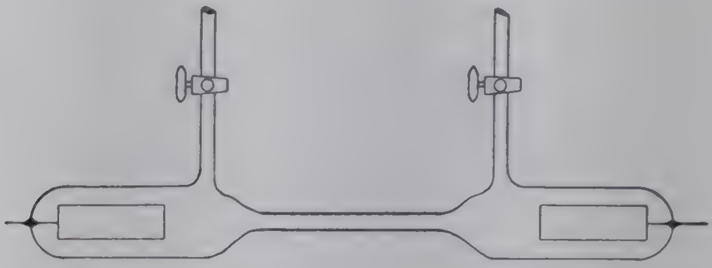

FIG. 3.37. Discharge tube for spectra of gases.

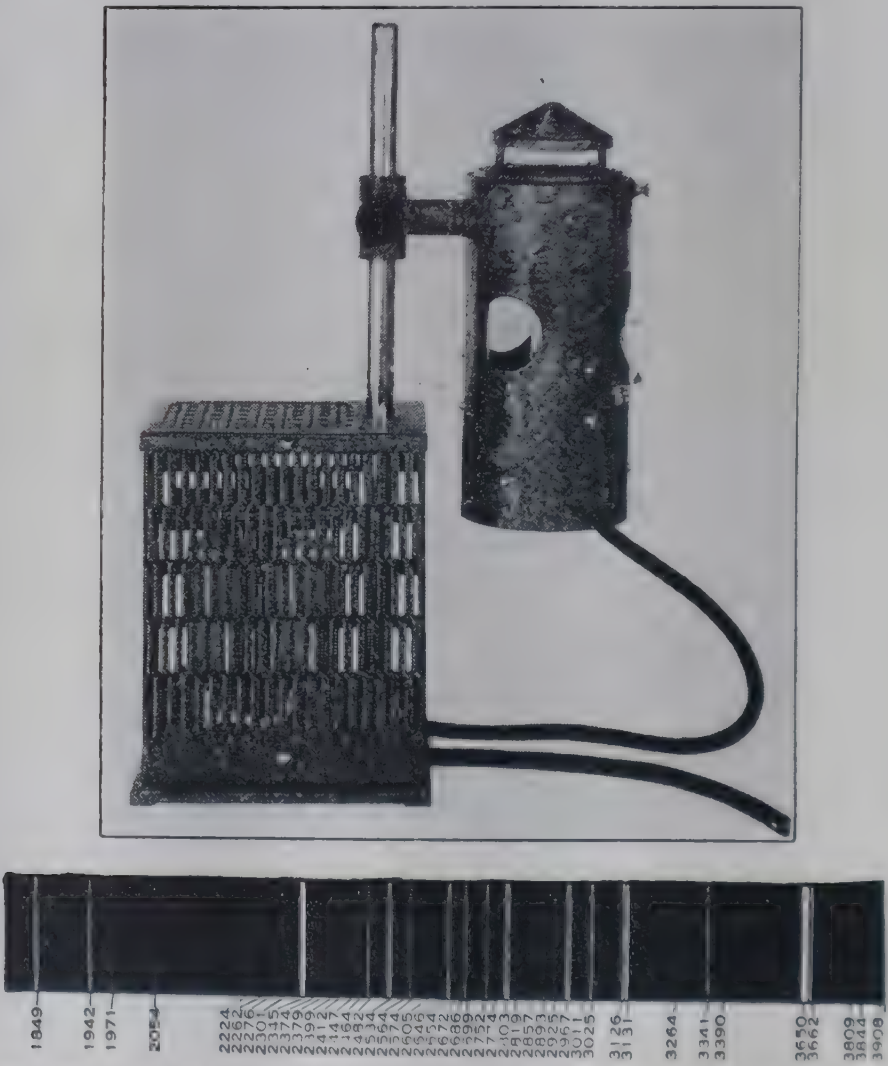

FIG. 3.38. Hanovia Mercury Labarc and ultraviolet spectrum produced. P.

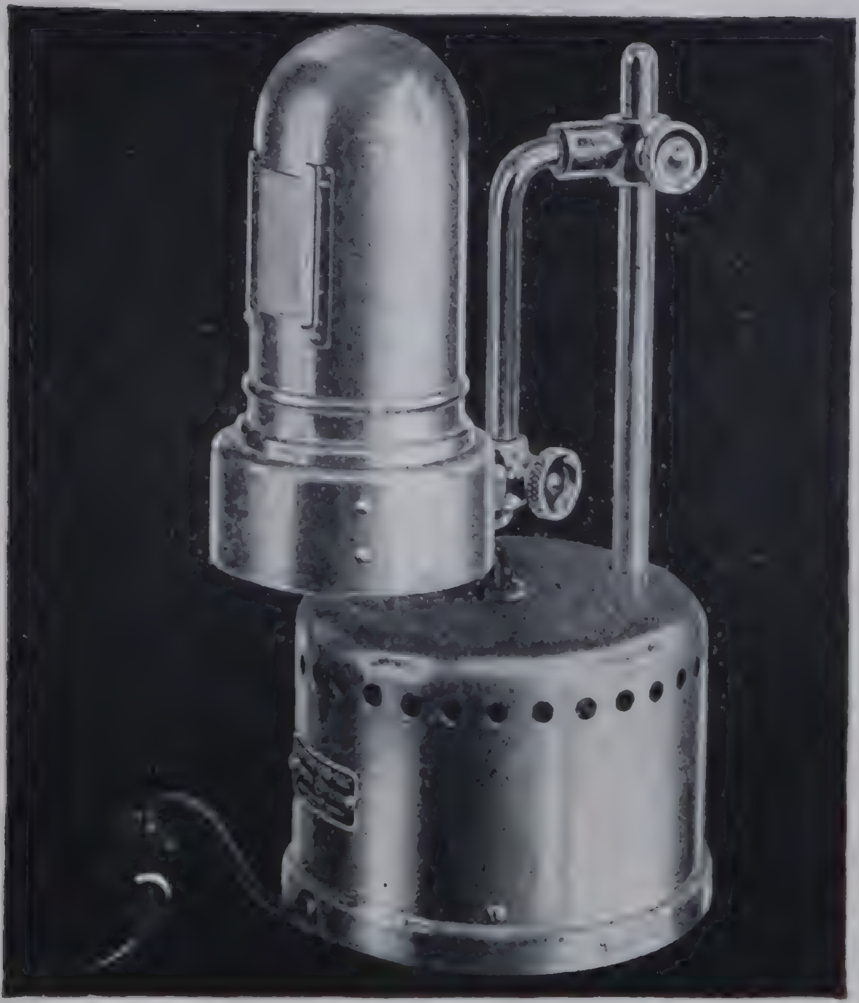

FIG. 3.39. Sodium vapor lamp (General Electric Vapor Lamp Company).

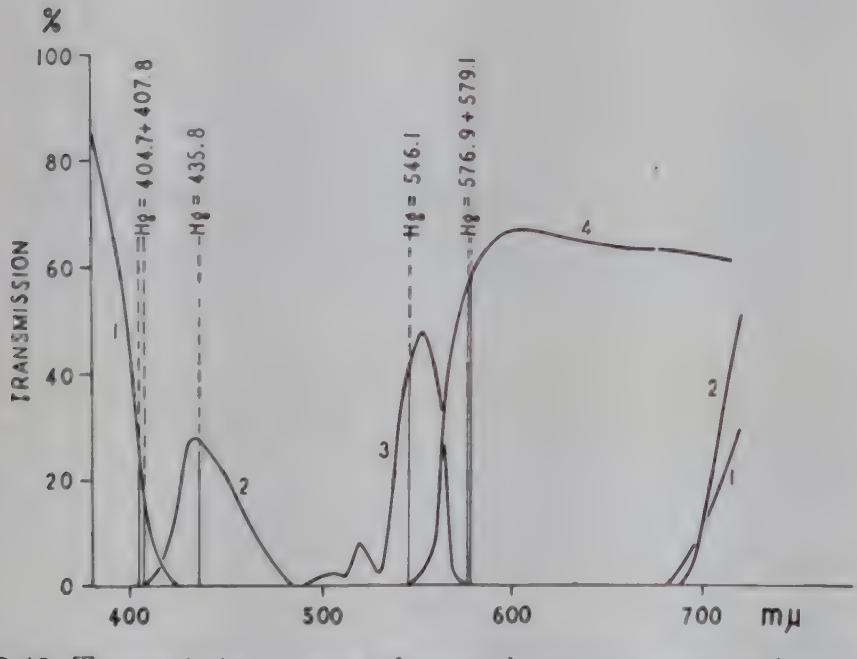

FIG. 3.40. Transmission curves of monochromatic mercury lamp filters.

1. Corning "G 586 A," 3.20 mm.
2. Corning "Noviol A," 2.00 mm. + "G 585," 4.62 mm.
3. Corning "G 555 P," 8.5 mm + "G 34," 2.25 mm.
4. Corning "G 36," 5.16 mm.

ments at the various mercury-line wavelength values. A glass envelope on the type H-4 lamp (see Fig. 3.41) absorbs considerable ultraviolet light, and it is suggested, if this lamp should be used for a calibration source in the ultraviolet, that the outer glass envelope be cut off.

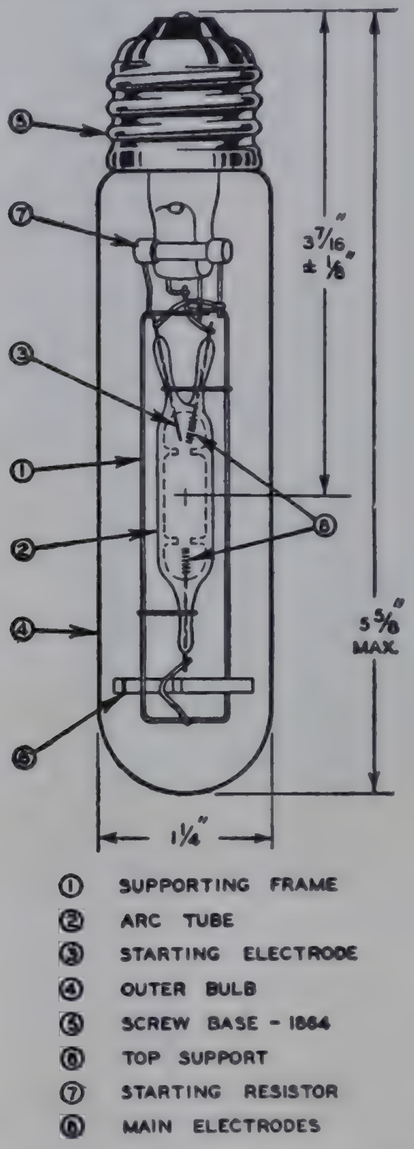

FIG. 3.41. Mercury-vapor lamp (Westinghouse).

LITERATURE

General

W. E. FORSYTHE and others, "Measurement of Radiant Energy" (*A23*).
F. WEIGERT, "Optische Methoden der Chemie" (*A99*).
F. TWYMAN, "The Spectrochemical Analysis of Metals and Alloys" (*A95*).

Reference

BALY (*A4*), WOOD (*A104*), TWYMAN (*A102*), SCHEIBE (*A81*), GERLACH (*A28*), (*A29*), MULLER (*C148*). Catalogs of Adam Hilger, Ltd.; Bausch and Lomb Optical Company; Carl Zeiss, Inc.; Gaertner Scientific Instrument Corporation; Baird Associates; Harry W. Dietert Company; Applied Research Laboratories; Spencer Lens Company; Jarrell-Ash Company.

CHAPTER IV

QUALITATIVE ANALYSIS, SPECTRUM TABLES, AND STANDARD SAMPLES

The application of spectroscopic methods to qualitative analysis dates from the work of Bunsen and Kirchhoff and other early investigators in the field of spectroscopy. The discovery that an element produced a characteristic spectrum quite naturally led to the idea that the same spectrum produced from an unknown was the result of the presence of that element in the unknown. Qualitative analysis was thus possible not only of substances immediately available to the chemist but also of any self-radiating body such as the sun or stars. The great developments in astrophysics have been largely the result of study of the spectra of stellar bodies. The temperatures, mass, distance, speed of travel, direction of rotation of eclipsing pairs, and many other important facts, as well as the chemical composition of the radiating body, are determinable from spectroscopic data (Fig. 4.1).

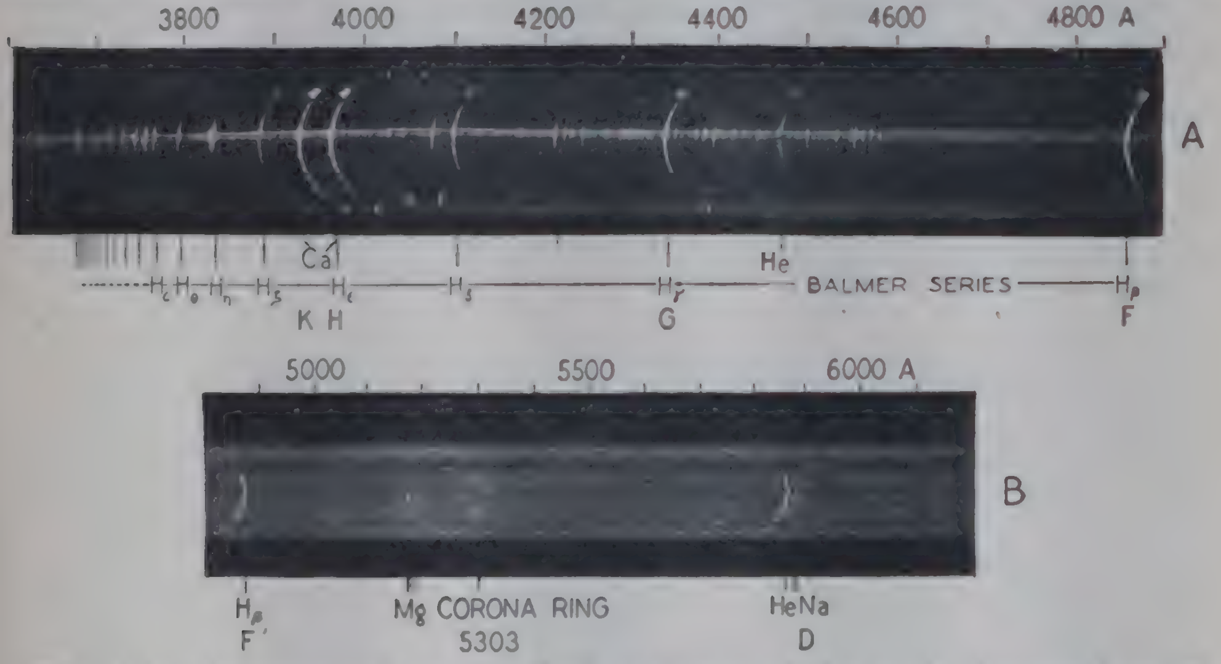

FIG. 4.1*a*. Astronomical spectra, flash spectrum of the sun's chromosphere. **P.** (Taken by Menzel, Boyce, Brode, et al., Harvard Observatory-Massachusetts Institute of Technology Eclipse of the Sun Expedition to Siberia, Ak Bulak, Kazahkstan, U.S.S.R., 1936.) (Note the Balmer hydrogen series and the ring due to Fe XIV (Edlén (*C78*) corona line.) *A*, third contact; *B*, second contact (inverted). (*C46*.)

As has been indicated in the discussion on the theory of line spectra (Chapter II), each element may be expected to give a large number of spectral lines, corresponding to the permitted electron transitions between various states and quantum values. In some elements such as hydrogen, sodium, copper, and mercury, one may expect a rather simple pattern of singlet, doublet, and triplet systems; but in other elements, such as iron, tungsten, and molybdenum, one finds a very complicated set of sextets, septets, and octets, and on account of this multiplicity there are a large number of lines. It is quite easy, then, to identify the

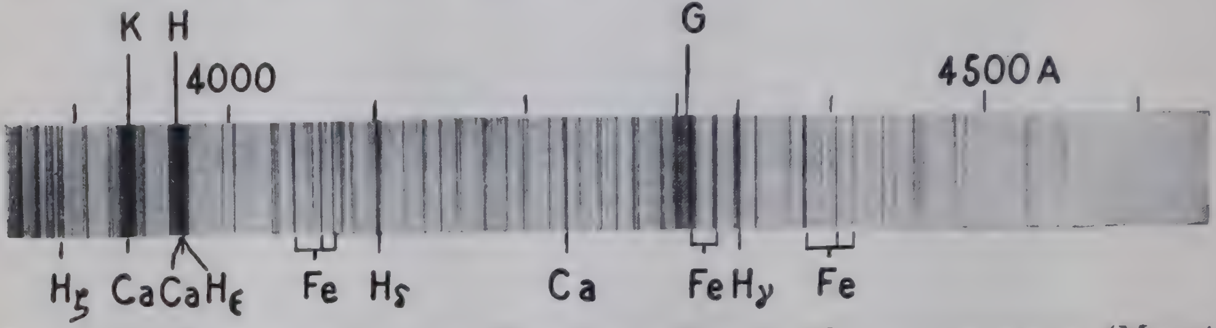

FIG. 4.1*b*. Astronomical spectra, Fraunhofer lines in the sun spectrum (Mount Wilson Observatory, Carnegie Institution of Washington). **P**

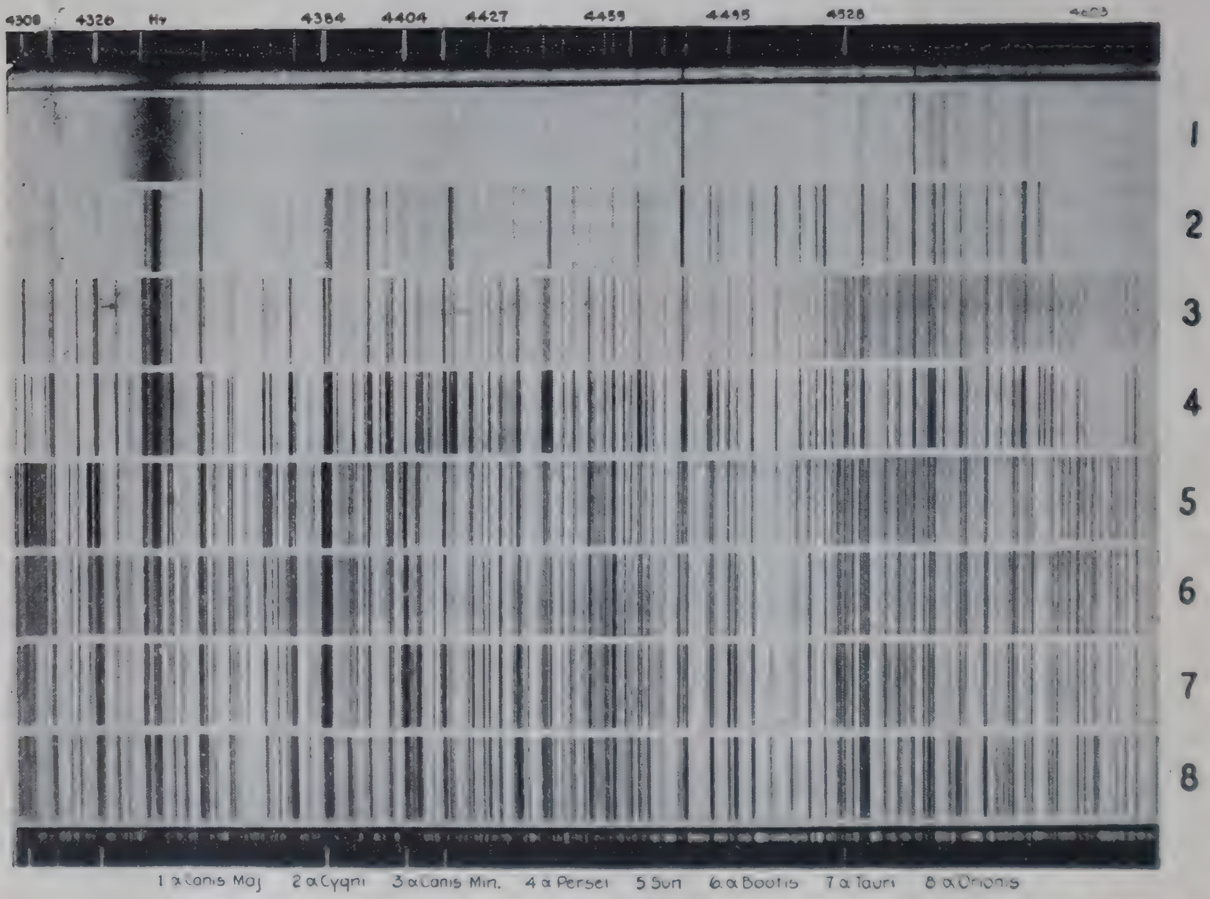

FIG. 4.1*c*. Astronomical spectra, widened prismatic coudé spectra of stars of different spectral types. (Region 4300 to 4600 A.) **N.** (Mount Wilson Observatory-Carnegie Institution of Washington.)

spectrum of a pure sample of any substance, and it is also quite easy to identify the constituent elements of mixtures of substances of simple spectra (Fig. 4.2).

It has been generally stated that spectrographic analysis is limited to some 70 of the 92 elements, but methods have been recently devised for spectrographic analysis of such non-metal elements as the halogens and sulfur (*C207*). The non-metal elements are more difficult to excite than the metal elements on account of a high ionization potential. The presence of more easily excited atoms tends to suppress the spectra of those elements that are difficult to excite; i.e., helium is suppressed by nitrogen, nitrogen is suppressed by mercury, and mercury is suppressed by potassium. The method proposed for I, Br, Cl, S, Se, O, N, and H involves the use of a reduced-pressure sparking chamber and a low-voltage exciting spark. The method is satisfactory for quantitative estimation as well as qualitative detection of these non-metal elements (*C160*).

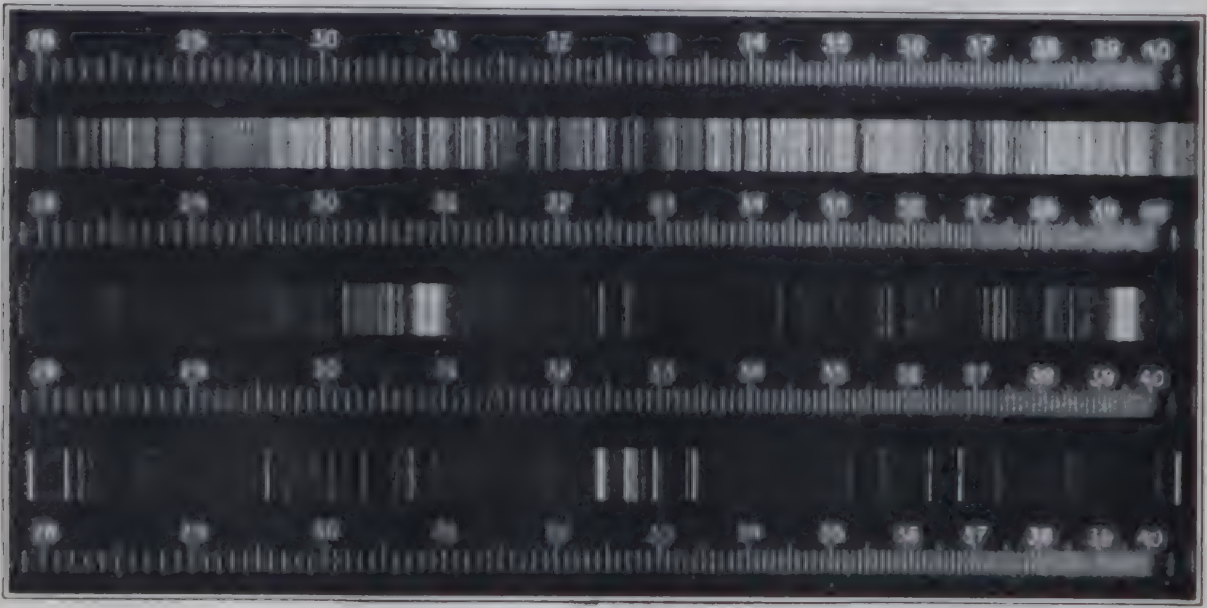

FIG. 4.2. Typical Spectrograms. P.
Top, steel; middle, aluminum alloy; bottom, brass.

STANDARD LINES

The actual procedure in the identification of a pure substance may be the comparison of spectra with a known pure sample of the same or suspected material, or one may measure the wavelength values of the observed lines and compare the measurements with the recorded data on known elements. The process of measuring the wavelength of a spectrum line may be accomplished by: (*a*) means of an interferometer and measurement directly of the wavelength of the line, (*b*) measurement of the relative position of the line between two known lines and interpolating the wavelength position, (*c*) the use of a wavelength scale which has been calibrated with the instrument and is photographically reproduced on the plate or visually observable in a direct observation, or (*d*) the superposition of a known spectrum with identified element lines either by projection of the spectrum or photographic recording in juxtaposition.

The measurement of lines by an interferometer method is very difficult and quite unnecessary for the identification of the wavelength of unknown lines in a qualitative analysis. The method is used, however, for the determination of the wavelength of a series of lines throughout the spectrum which are known as the primary and secondary standards. The primary standard has been chosen as the red line of cadmium, which appears even in high resolution to be a single line. The wavelength of this line has been agreed upon as 6438.4696A in dry air at 15° C and 760 mm pressure, the radiation being produced in a vacuum tube with electrodes. The selection and approval of such standards have been largely the work of astronomers and spectroscopists connected with the former International Union for Cooperation in Solar Research and the present International Astronomical Union, through a committee which is now headed by Dr. W. F. Meggers of the National Bureau of Standards. The angstrom instead of being defined as 10^{-10} meter is now more accurately defined as 1/6438.4696 of the wavelength of the cadmium red line. The accuracy of this determination is about 1 part in 10,000,000. For all practical purposes and for ease in indication, the angstrom may still be considered as equivalent to 10^{-10} meter.

A group of lines, for which three independent observers have obtained concordant results through interferometric measurement, have been accepted as the secondary standards (Table VI, lines indicated by "+"), and from these another set of lines has been measured by a process of interpolation, this latter set being known as tertiary standards (Table VI, lines indicated by "°"). Nearly all the secondary and tertiary lines are iron lines. Iron has been used extensively as a spectrographic standard because of the ease in obtaining pure samples, and also because it has a very large number of lines within the photographic ranges and the solar spectrum region (5500–3700 A). With an extension of the photographic methods in both the infrared and ultraviolet regions, it has been found necessary to include other element lines such as neon and copper, to cover those parts of the spectrum where iron fails to give a sufficient number of lines.

These secondary standards do not supply a sufficient number of lines for convenient and accurate determination of the wavelength of unknown lines, and hence additional standards are often determined and accepted. Tertiary standards are determined by accurate interpolation measurements between the known or secondary standard lines. (*C133.*)

Following the work of Bunsen and Kirchhoff, Ångström measured accurately with three different gratings the wavelength values of the lines in the sun spectrum (Fraunhofer lines), and his assistant Thalen measured the principal lines of the then known metallic elements (44). Owing to an erroneous measurement of the length of the meter at Upsala as compared with the Paris meter, his values were found to be in error and he and his assistant corrected the original calculations so that the final work marked the first accurate reference map and element tabulation for spectrographic analysis. Cornu, in 1874–1880, published an extension of the Ångström solar map by a photographic method to include the near ultraviolet region. Other important contributions to the field of spectroscopy and the extension of the spectral data beyond the visible regions were made by William Herschel, John Herschel, and Langley.

A definite improvement in accuracy was made in the solar spectrum map which was produced by Rowland through the use of gratings which he prepared. As the standard wavelength for his determinations, Rowland accepted the value 5896.156 A for the sodium D line, a value which was the mean of a number of workers' observations, and which he felt, if ever shown to be in error, would require only a uniform correction of his data. Unfortunately, Rowland's data (1893), although the most accurately determined material of its kind, had a periodic error which is greater than the experimental error with our improved present-day technique. Rowland's date have been corrected by members of the Mount Wilson Observatory Staff and published by the Carnegie Institution of Washington (*A80*).

In 1894, Michelson, by means of an interferometer, determined accurately the wavelength values of three of the cadmium lines in the red, green, and blue portions of the spectrum and showed that these values did not agree with the Rowland map values within the limits of experimental error. The accuracy of interferometric measurements leaves no doubt but that measurements by this method are more acceptable than those made from calculation of grating space and relative dispersion. In view of the accuracy of the Michelson and the Fabry and Perot interferometric determinations on the red cadmium line, it has been agreed that this line shall be used as the primary spectroscopic standard. The accuracy of determination of this value is about 1 part in 10,000,000, which is comparable with that of the measurement of the standard meter. The accepted value of 6438.4696 A for the cadmium red line also becomes the definition of the angstrom, in terms of the wavelength of this line.

Tables of Spectrum Lines Arranged by Elements or Wavelength

The available lists of spectrum lines may be separated into two groups: those of a more condensed nature (*I*), and those which have attempted to cover all data of a known accuracy (*II*).

*I. Condensed Spectrum Line Tables**

1. Boyce, J. C., "Spectroscopy in the Vacuum Ultraviolet" (1941) (*C12*). Includes wavelength standards in ultraviolet and an extensive bibliography (23 pages) arranged by element. (See also Lyman, T., "Spectroscopy of the Extreme Ultraviolet" [1928] [*A69*].)

2. Brode, W. R. The spectrum tables in this book, pp. 400 to 610, which have been selected from Harrison (**11**) and other sources. These tables include principal lines of 85 elements, arranged according to elements, giving arc and spark lines on an intensity scale of 1 to 9000, and a table of the principal lines of 85 elements arranged according to wavelength, giving arc lines on an intensity scale of 10 to 9000.

3. Crook, W. J., "Tables of Arc Spectrum Lines Arranged in Order of Wavelength" (1933) (*A14*), and "Metallurgical Spectrum Analysis" (1935) (*A13*). Wavelengths arranged from 2800 to 3500 A and 2500 to 5670 A.

4. Eder, J. M., and Valenta, E., "Atlas typischer Spektren" (1911) (*A16*). Contains about 35,000 lines in the range 7950 to 1850 A, in arc, spark, and flame, for 75 elements, given to 0.01 A, with intensity range 1 to 100. Contains also some bandheads. Data in Rowland scale.

5. Exner, F., and Haschek, E., "Die Spektren der Elemente bei normalen Druck," Vol. I, Deuticke, Leipzig (1911) (*A19*).

6. Gatterer, A., and Junkes, J., "Atlas der Restlinien" (1937) (*A26*). Contains about 2400 lines in the range 8100 to 2200 A, in arc and spark, for 30 elements, given to 0.01 A. Contains also some band spectra.

7. "Handbook of Chemistry," 2nd and 3rd editions, N. A. Lange, editor (*A36*). "Wavelength of the Principal Lines in the Emission Spectra of the Elements" by J. A. Hannum in 2nd and 3rd editions (1937) (1939), listing 5000 of the principal lines of 83 elements from 124 to 90,850 A (this table does not appear in the 4th edition.)

8. "Handbook of Chemistry," 4th edition, N. A. Lange, editor (1941) (*A36*). "Qualitative Spectrographic Analysis Table" by F. H. Emery on pp. 891–908. A list of the persistent lines of 55 elements together with interfering adjacent lines of other elements.

9. "Handbook of Chemistry and Physics," 25th edition, C. D. Hodgman, editor (1941) (*A35*). Contains the spectral lines given in the International Critical Tables (see item **12** below) and, in addition, more extended tables on A, As, B, Ba, Br, Ca, C, Cl, Cr, Cb, Cu, Hf, He, Fe, Kr, La, Mn, Ne, K, Re, Rb, Si, Na, Sr, Ta, Ti, W, V, Xe, Yb, Y, Zr, being for the most part a selected list of lines as published by Meggers, Kiess, and their associates in the *Bureau of Standards Journal of Research*. Separate tables are also given of the primary, secondary, and tertiary standards.

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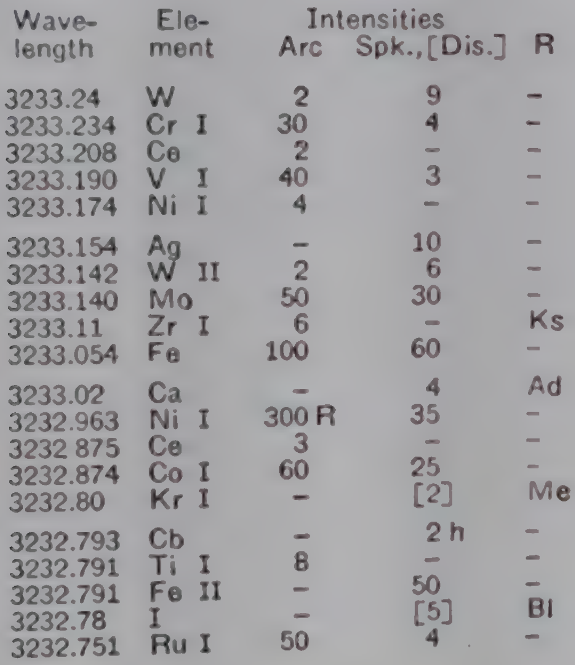
* See the Bibliography (pp. 383–397) for complete publication data on these and other references. The Bibliography is divided into three parts; *A*, *Theory of spectra and emission analysis; B*, *Absorption spectra;* and *C*, *Research publications and journal articles.* In each of these divisions the references are arranged in alphabetical order.

10. Gerlach, W., and Riedl, E., "Tabellen zur qualitativen Analyse" (in Vol. III of "Die chemische Emissionsspektralanalyse" by Gerlach [1936]). A table of the principal lines of 57 elements, arranged according to elements, with recommended control lines and possible interfering lines (*A29*).

11. Harrison, G. R., "M. I. T. Wavelength Tables of 100,000 Spectrum Lines" (1939) (Fig. 4.3) (*A39*). A table of 100,000 lines from 2000 to 10,000 A arranged according to wavelength with an intensity range from 1 to 9000. From the Spectroscopy Laboratory of the Massachusetts Institute of Technology with the assistance of the Works Progress Administration.



Wave-length	Ele-ment	Intensities		
		Arc	Spk.,[Dis.]	R
3233.24	W	2	9	–
3233.234	Cr I	30	4	–
3233.208	Ce	2	–	–
3233.190	V I	40	3	–
3233.174	Ni I	4	–	–
3233.154	Ag	–	10	–
3233.142	W II	2	6	–
3233.140	Mo	50	30	–
3233.11	Zr I	6	–	Ks
3233.054	Fe	100	60	–
3233.02	Ca	–	4	Ad
3232.963	Ni I	300 R	35	–
3232 875	Ce	3	–	–
3232.874	Co I	60	25	–
3232.80	Kr I	–	[2]	Me
3232.793	Cb	–	2 h	–
3232.791	Ti I	8	–	–
3232.791	Fe II	–	50	–
3232.78	I	–	[5]	Bl
3232.751	Ru I	50	4	–

Fig. 4.3. Portion of a page from the M. I. T.-Harrison 100,000 line tables (*A39*).

12. Kayser, H., "Emission Spectra of Elementary Substances" (in Vol. 5, pp. 276–322, of the "International Critical Tables" [1929]). (*A53*.)

13. Kayser, H., "Tabelle der Hauptlinien der Linienspektra aller Elemente" (1926) (*A55*). A table of 19,000 lines representing 91 elements, arranged according to wavelength; a standard work for qualitative identification of arc and spark lines with intensities given on a 0 to 10 scale.

14. Kayser, H., and Ritschl, R., "Tabelle der Hauptlinien der Linienspektra aller Elemente," 2nd Edition (1939) (*A56*). Contains 27,000 lines. Intensities are given for arc lines only except those lines which are only produced in sparks on an intensity scale of 0 to 1000.

15. Löwe, F., "Atlas der letzen Linien der wichtigsten Elemente." A table of 700 of the persistent arc and spark spectrum lines of the more important elements (1928) (*A66*).

16. MEGGERS, W. F., "Notes on the Physical Basis for Spectrographic Analysis" and "The Strongest Lines of Singly Ionized Atoms" (1941) (*C136*).

17. MEGGERS, W. F., and SCRIBNER, B. F., "Residual Arc Spectra." Tables of 70 elements giving the sensitive lines in an arc source (unpublished data compiled at the Bureau of Standards) (*C138*).

18. PEARSE, R. W. B., and GAYDON, A. G., "The Identification of Molecular Spectra." A list of band heads from 2000 to 10,000 A of diatomic molecules and a few triatomic and polyatomic molecules. Includes conversion tables of wavelengths on Rowland's scale to international angstroms and conversion of wavelengths in air to wavelengths in vacuum. A useful table for the identification of band spectra in atomic spectra analysis (1941) (*A77*).

19. SCHEIBE, G., "Chemische Spektralanalyse" (in "Physikalische Methoden der analytischen Chemie" edited by W. BÖTTGER, Vol. I, p. 66–92 [1933]). A table of the principal lines of 62 elements, arranged according to wavelength, giving arc, spark, and flame lines on an intensity scale of 1 to 10 (*A81*).

20. SMITH, D. M., "Visual Lines for Spectrum Analysis" (1928) (*A86*).

21. TWYMAN, F., and SMITH, D. M., "Wavelength Tables for Spectrum Analysis." These tables include (*a*) the distinctive lines in the spark spectra by Hartley, Pollok, and Leonard; (*b*) the *raies ultimes* by de Gramont; (*c*) the sensitive lines by Ryde and Jenkins; and (*d*) the flame spectra lines by Lundegardh (1931) (*A94*).

II. Extended Spectrum Line Tables and Critical Compilations of Emission Spectrum Data

22. EXNER, F., and HASCHEK, E., "Die Spektren der Elemente bei Normalen Druck," Vols. II and III (1911). The spectra of 77 elements, arranged according to elements, giving over 120,000 lines in arc and spark spectra on an intensity scale of 1 to 1000. (Wavelength values based on the Rowland scale.) (*A19*.)

23. HARRISON-M.I.T.-W.P.A. data. A card catalogue of recorded lines of elements, arranged by elements, from which a partial selection of lines was made and arranged by wavelength and published (*C99*) (*A39*).

24. KAYSER, H., "Handbuch der Spektroscopie," Vols. V (1910), VI (1912), VII (1934), and VIII (1932), contains the most complete collected data on wavelength and intensity values of spectrum lines. The work is still quite incomplete as no data for 40 elements (from Nd to Zr) have been published since 1911 (*A52*).

25. "Physikalische-Chemische Tabellen," LANDOLT-BORNSTEIN, edited by W. A. ROTH and K. SCHEEL, 5th edition (1923), and three supplementary editions covering the literature to 1934. These tables include an extended section on emission spectra and line spectra term analysis (*A62*).

26. "Tables annuelles de constantes et données numériques," section of emission spectra in Vols. I to XII (covering the literature from 1910 to 1936) giving about 800 pages of collected data (*A91*).

Many papers on spectrum lines and their analysis into systems have appeared since the last data covered in the above general compilations. Such papers are best located through a search of *Chemical Abstracts*, *Science Abstracts*, and current journals, especially *Astro. Phys. J.*, *Phys. Rev.*, *Z. Physik*, and *Bureau of Standards Journal of Research*. As examples of such papers, the following recent publications may be cited:

"Spectrum of Au" by J. R. Platt and R. A. Sawyer, *Phys. Rev.*, **60**, 866 (1941), including some 2000 new lines in the region 600 to 10,000 A.

"Spectrum of Pr II" by N. Rosen, G. R. Harrison, and J. R. McNally, *Phys. Rev.*, **60**, 722 (1941).

"Spectrum of Eu II" by H. N. Russel, W. Albertson, and D. N. David, *Phys. Rev.*, **60**, 641 (1941).

Inasmuch as the data recorded in all these tables tend to become identical, the choice of the table to use will depend largely on the accuracy with which the analysis is to be made. The best published collections available up to 1939 are the Kayser-Konen "Handbuch der Spektroscopie" (**24**) for the wavelength spectra according to elements, and the Kayser "Hauptlinien" tables (**14**) for the elements arranged according to wavelength. However, in view of the fact that most of the tables indicated in the above list have a common origin, there have been a number of errors and omissions which have been carried over from one table to another. The recent publication of the 100,000-line list by Harrison provides a new source of spectroscopic data which has been measured directly from spectrum plates by an automatic-recording plate-reading instrument. From the data obtained by these recording instruments 100,000 lines have been selected as material for this table. The intensities of these lines are also recorded by a photographic device, and hence the data are independent of personal error in judgment of intensities. The tables in the fourth edition of the "Handbook of Chemistry" and those in this book (pages 400–610) are devised from the M.I.T.-Harrison tables. For most analytical purposes, however, the tables available in the chemical handbooks (**7**, **8**, and **9**), the Twyman and Smith tables (**21**), the Scheibe tables (**19**), or the tables in this book (**2**) should be adequate.

Photographic Tables and Charts

In addition to the numerical tables which have been described, a number of photographic tables are available. These may be divided into two types in accordance with their character or method of presentation.

In the making of halftone reproductions of spectrum line photographs, especially where reduction of the original is involved, there is considerable loss in line definition; this should be realized when reference is made to the examples in this text. This difficulty in reproduction of spectrograms should be considered in the obtaining of reference charts for laboratory use. The photographic print, though superior in definition to the halftone reproduction of the spectrogram, has only about a tenth the latitude of the usual photographic negative. It may be necessary to reproduce spectrograms of different exposure times (as in the Gatterer and Junkers charts [**28** and **29**]) so as to extend the latitude of the paper print to more nearly that of a single negative spectrogram.

III. Spectrograms of Elements

(Separate photographs of the spectrum of each element)

This form of graphical presentation of data is analogous to the tabular system in which the numerical data are arranged in separate tables for each element.

27. Eder, J. M., and Valenta, E., "Atlas typischer Spektren" (1911). Tables of flame, arc, and spark spectra **N** taken with glass prism, quartz prism, and grating. Includes 53 cards (12 by 16 inches) with 12 spectrograms on each card (*A16*) (Rowland wavelength scale).

28. Gatterer, A., and Junkers, J., "Atlas der Restlinien" (1937). Tables of the principal lines of 50 elements and 28 photographic charts (12 by 16 inches) with 6 spectrograms per chart. Photographs taken with prism dispersion including arc and spark spectrograms from 2200 to 8000 A (Fig. 4.4*a*) **N** (*A26*).

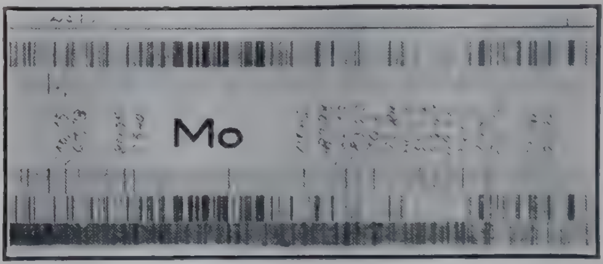


Fig. 4.4*a*. *Atlas der Restlinien* chart by Gatterer and Junkers (*A26*) showing spectrum arrangement of iron, short exposure, wavelength values, medium exposure, iron, and long exposure. Illustration shows about one fourth of a single element section reduced to half scale. **N.**

29. Gatterer, A., and Junkers, J., "Arc spectrum of Iron from 8388 to 2242 A" with "Spark Spectrum of Iron from 4650 to 2242 A" (1935). A set of 21 photographic charts (7 by 9.5 inches) taken with prism dispersion (Fig. 4.4*b*) **N** (*A27*).

30. Hilger, Spectrogram of Iron. A set of mounted photographic copies of a prism dispersion iron spectrogram **P** with the wavelength positions of the lines indicated. Eight cards (8 by 14 inches) (new edition 1937) (Fig. 4.4*c*) (*A42*).

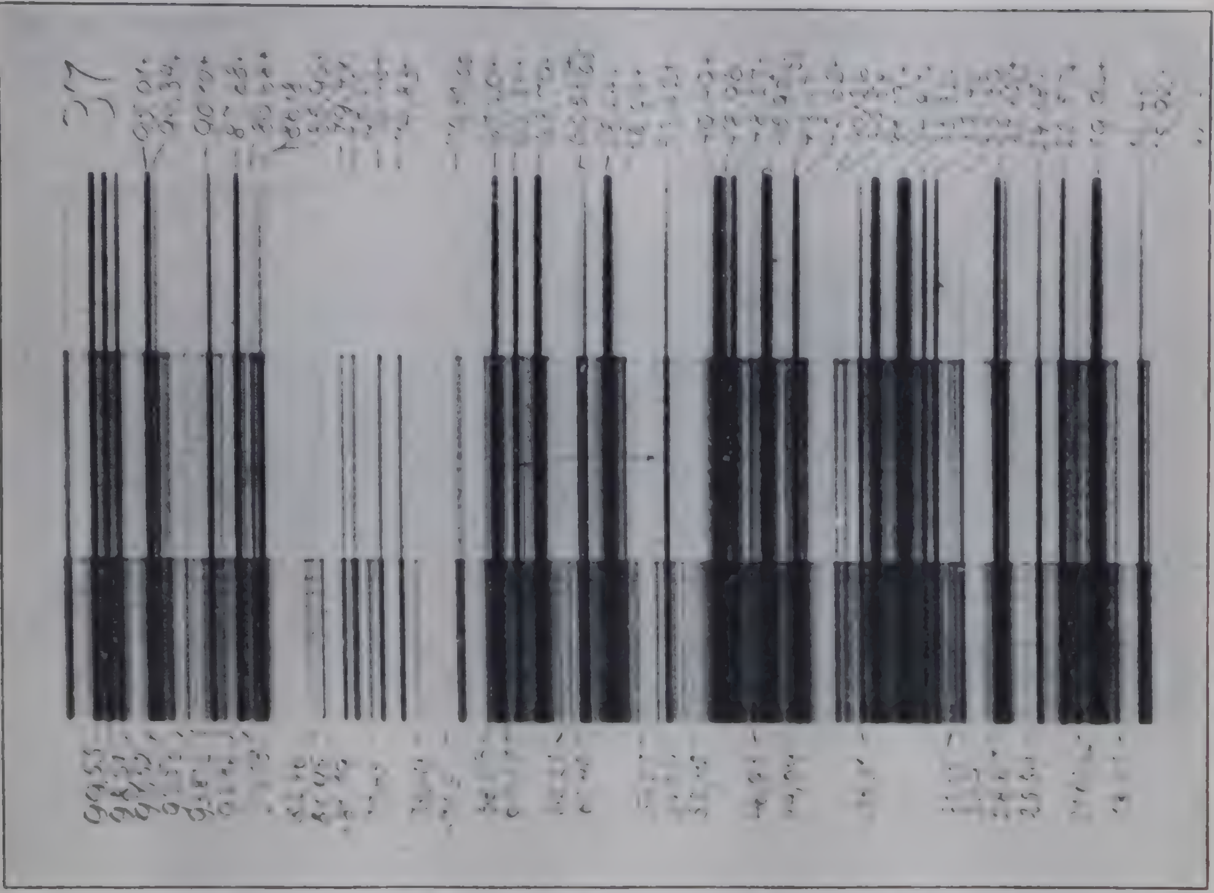


FIG. 4.4*b*. Arc spectrum of iron by Gatterer and Junkers (*A27*) showing short, medium, and long exposures. Illustration shows one half of one of the 21 charts on a slightly reduced scale. **N.**

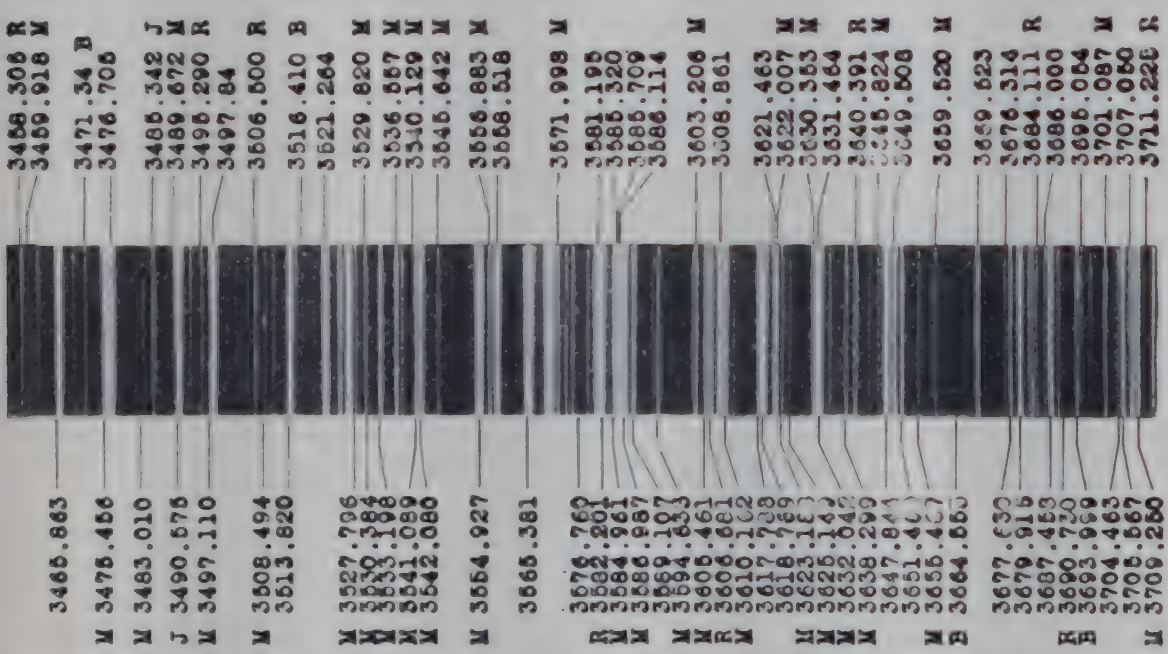


FIG. 4.4*c*. Iron spectrum chart (Hilger). P. Prism dispersion (*A42*). Portion of series of 8 charts. Illustration shows one third of a chart reduced to half scale.

31. Hilger, Spectrogram of Copper. An enlarged spectrogram of copper from 2043 to 5782 A. Three cards (6 by 14 inches) (Fig. 4.4*d*) **N** (*A43*).

32. Hilger, Spectrogram of Neon. Enlarged spectrogram on a card (5 by 8 inches) showing 20 lines from 5850 to 7032 A **P** (*A44*).

33. Hilger, Spectrogram of Helium. Enlarged spectrogram on a card (4 by 12 inches) showing 19 lines between 3610 and 7282 A **P** (*A45*).

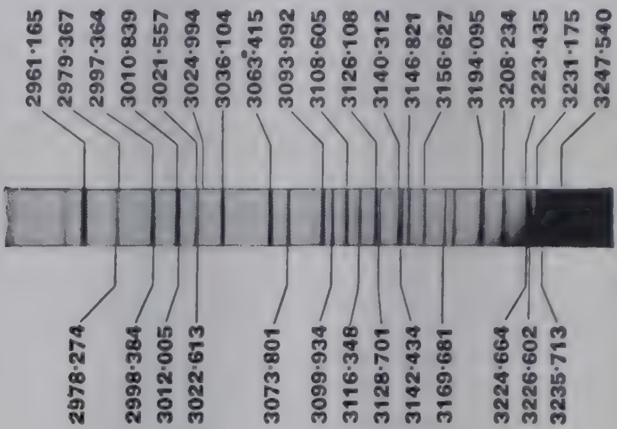


Fig. 4.4*d*. Spectrogram of copper (Hilger) (*A43*). Portion of a series of three charts. Illustration shows about one fifth of a chart on a slightly reduced scale. **N.**

34. Löwe, F., "Atlas der letzten Linien der wichtigsten Elemente" (1928). A set of 16 charts giving portions of the spectra of 50 elements as obtained in spark and arc spectra together with a table of about 700 of the persistent lines of the elements arranged according to wavelength **N** (*A66*).

35. Lundegårdh, H., "Die quantitative Spektralanalyse der Elemente," Part I (1929). As a supplement to this volume are included photographic charts of 30 elements giving the flame spectra of their salts at various concentrations together with a numerical table of spectral lines arranged according to elements **N** (*A68*).

36. Lundegårdh, H., "Die quantitative Spektralanalyse der Elemente," Part II (1934). Photographic charts are included of the spark spectra of 22 elements together with a table of lines of 64 elements giving selected lines for identification (see Fig. 5.23) **N** (*A68*).

37. Harrison, G. R., An iron arc spectrum chart comprising 18 cards (each 20 inches in length) prepared by direct printing from spectrograms made on a 10-meter focal length, 30,000-line grating, is especially valuable for workers using higher orders of grating instruments since it charts three overlapping orders **N** (*A40*).

IV. Composite Spectrogram of Elements

Composite spectrogram data may be subdivided into two types: *a*, spectrograms obtained from a mixed source; and *b*, indicated positions adjacent to an iron spectrum or scale indicating where other element lines would appear if present in a spectrogram.

a. Spectrograms from a mixed source

38. HILGER, Spectrogram of R. U. Powder. A set of 7 enlarged photographs **P** of the spectrogram (prism dispersion) of a sample of R. U. (raies ultimes) powder with the identified principal lines of 50 elements (Fig. 4.4*e*) (*A46*).

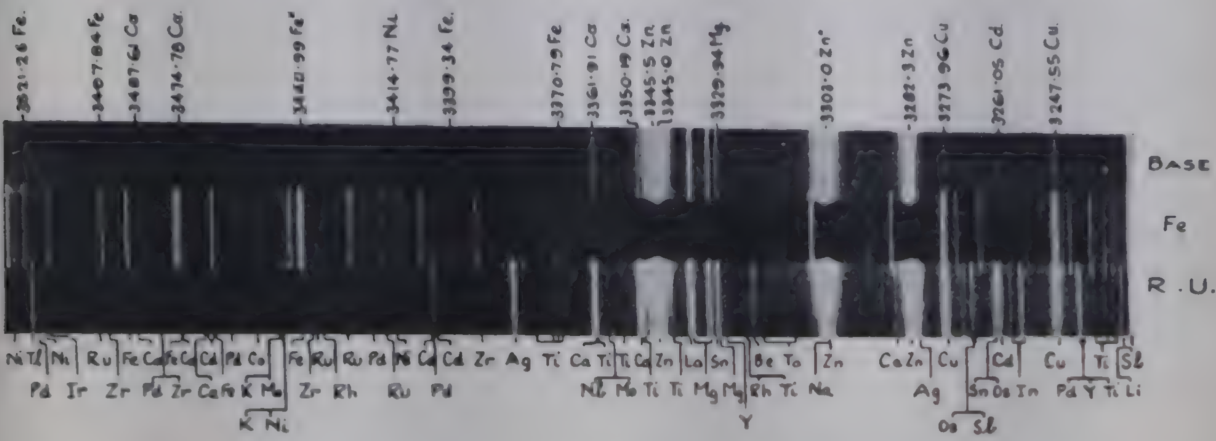


FIG. 4.4*e*. Portion of one of the Hilger Raies Ultimes charts. Spectra of the principal lines of most of the common elements (*A46*). **P**. A series of 7 charts. Illustration shows one third of a chart reduced to half scale.

39. ROWLAND and others, tables and charts of the lines in the sun spectrum, revised (1928) by members of the staff of the Mount Wilson Observatory, Carnegie Institution of Washington (*A80*).

b. Iron spectrograms with indicated positions of other elements

40. BARDET, J., "Atlas de spectres d'arc" (1926). Charts of persistent lines with an iron reference spectrum arranged according to (*A*) wavelength, and (*B*) important elements. Includes 54 charts (7 by 9½ inches) with the iron spectrum (prism dispersion) reproduced from 2500 to 3500 A **N** (*A5*).

41. BRODE, W. R., A set of 35 charts (7 by 9 inches) with the iron arc spectrum reproduced **P** from 2300 to 5000 A. The positions of the principal lines of other elements are indicated, Plates II to XXXVI in this book (Fig. 4.6).

42. BUISSON, H., and FABRY, CH., "Spectre du fer." A set of 7 charts reproducing the arc spectrum of iron as obtained on a grating instrument and reproduced with a dispersion of about 1 angstrom per mm **P** (*A8*).

43. CROOK, W. J., "Metallurgical Spectrum Analysis." Tables and charts of the iron spectrum. Includes 24 charts (11 by 14 inches) with iron spectrum (grating dispersion) **N** with indicated positions of the principal lines of other metallic elements (2800 to 3500 A and 5000 to 5670 A), a separate iron spectrum **P** covering the same range, and tables of the principal lines of other elements within these spectral limits (Fig. 4.5.) (*A13*).

44. PIERCE, W. C., TORRES, O. R., and MARSHALL, W. W., "Identification of Lines in Qualitative Spectrographic Analysis." Charts giving a wavelength scale, an iron arc reference spectrum, and analysis lines for 47 elements for the region 2500 to 5150 A. Similar charts with extensions to cover the range from 2100 to 7000 A (W. R. Brode) are given in Plates XXXVII to XL in this book (*C162*).

45. SCHEIBE, G., and LINSTROM, C. F., "Tabellen des Funken- und Bogenspektrums des Eisens zur Wellenlangenbestimmung bei der technischen Emissions-Spektralanalyse" (1933). Tables of wavelengths of spectrum lines from 2300 to 3700 A with spectrum charts of arc and spark spectra. The charts reproduced on 5 by 7 sheets include the arc and spark photographs of iron in juxtaposition. The photographs are taken on a quartz instrument giving a reproduced dispersion of about 140 cm between 2300 and 3700 A **N** (*A83*).

Continued use of charts of both prismatic and grating origin indicates that it is not at all impossible to use prismatic charts with grating spectrograms, or vice versa, for the purpose of identifying lines, although it must be admitted that the identification is easier when the chart and spectrogram are produced by the same dispersion method.

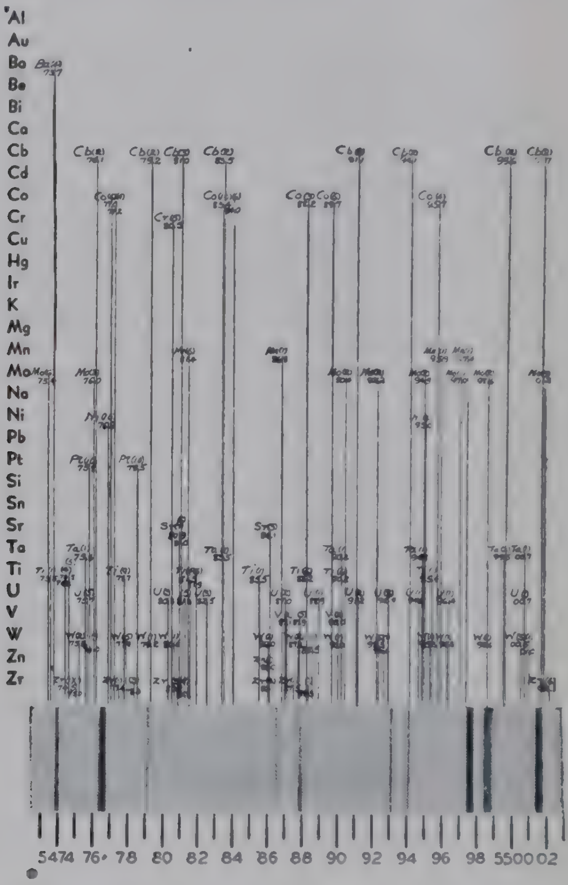


FIG. 4.5. Iron—unknown spectrum chart (Crook). **N**. Grating dispersion (*A14*). Portion of series of 20 charts. Illustration shows one-half of a chart reduced to one-third scale.

The available charts which correspond to the numerical tabulation of lines of all elements arranged according to wavelength, rather than those arranged according to elements, are of two types: those showing the principal lines of a large number of elements, and those showing only the iron spectrum and the indicated position where the principal lines of elements would be if they were present in the spectrum. The use of

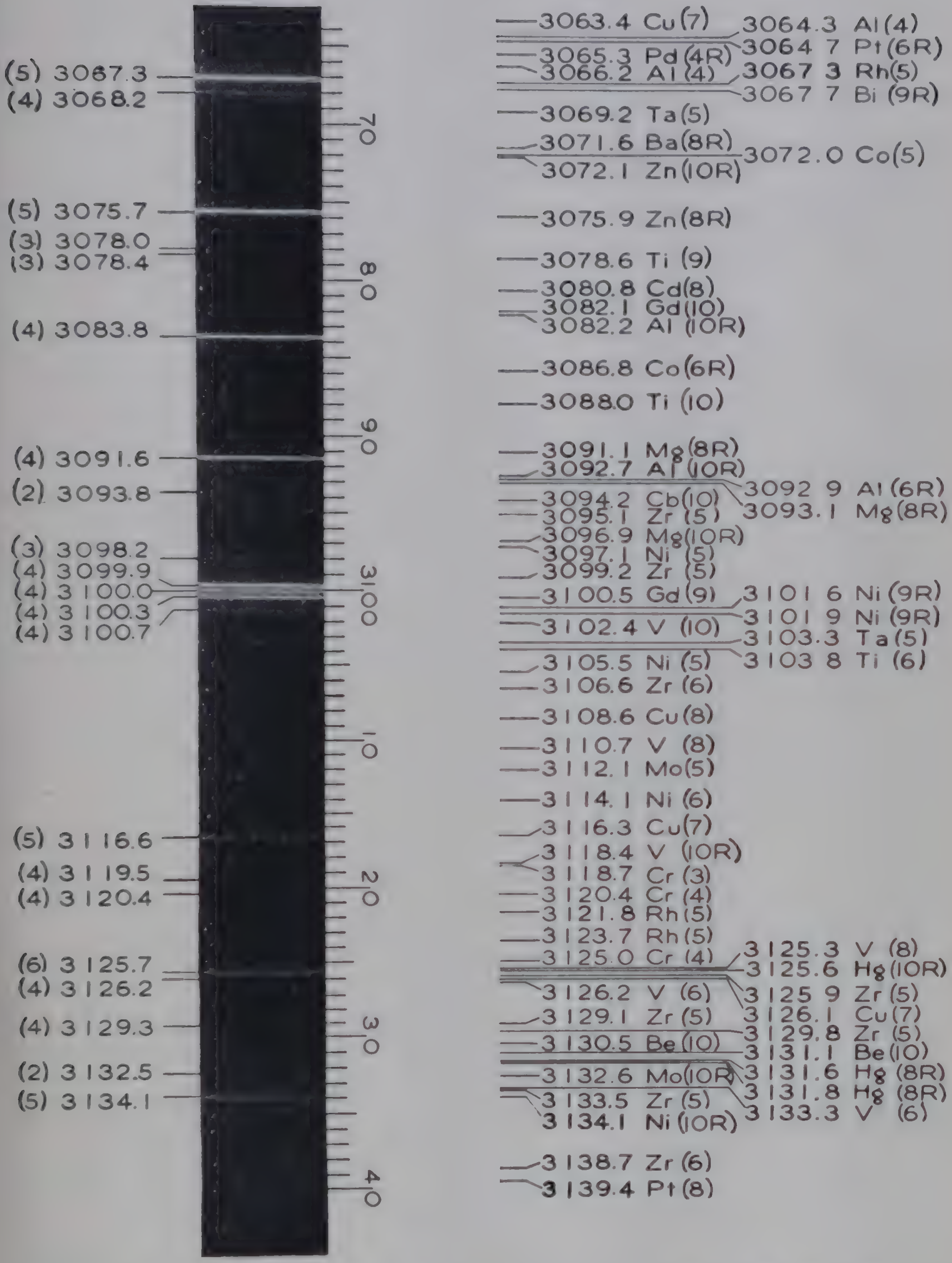


FIG. 4.6. Chart for spectral analysis with iron comparison (Brode). P. (See Plates II to XXXVI in this book for complete series.)

iron in this way essentially constitutes a very finely divided though somewhat irregular scale which can be impressed or printed in juxtaposition to, or partially overlapping, the unknown spectrum, and thus serves to locate the position of unknown lines.

The selection of the lines to appear in charts of the first type which give only a few lines of all the elements is dependent on a principle proposed by de Gramont, known as the *raies ultimes*, which will be discussed later in this chapter, but for the moment we may accept these as the most persistent lines of the various elements which are included. An excellent chart of this type, known as the raies ultimes chart (**38**), is available from Adam Hilger, and in addition, this company has prepared a powder of a large number of elements so as to enable workers to prepare their own negatives for direct photographic or projection comparison (Fig. 4.4*e*).

The second type of chart, that of an iron spectrum with indicated positions of lines of other elements, is of importance in the rapid identification of lines in qualitative analysis of unknowns. Three charts of this type are available; two of which, the Bardet (**40**) and those in this book (**41**), are for prismatic instruments, while the Crook (**43**) (Fig. 4.5) is for a grating dispersion. The Bardet table is limited to a range from 2500 to 3570 A, and the Crook table from 2790 to 3430 A and from 5050 to 5670 A. Those in this book have been designed to cover a wider range, from 2310 to 5080 A, and in addition, supplementary charts patterned after those of Pierce (**44**) have been added to cover the range from 2100 to 7000 A (Plates XXXVII to XL).

PERSISTENT LINES (RAIES ULTIMES)

All these iron-unknown tables give line intensities as well as position of the unknown lines. The selection of lines for inclusion in such tables is usually the somewhat random choice of the compiler of the table, although an attempt is made to include the strongest lines of all the possible elements. Outside the tables of persistent lines or the raies ultimes there has been no attempt to prepare condensed tables and charts based on a nonarbitrary selection, except in the tables of Meggers (**17**), in which the "residual lines" are selected in accordance with their presence in diluted samples in arc spectra.

De Gramont has suggested a special name for the most persistent lines of an element: *raies ultimes*; they are also known as the *letzten Linien*, the persistent lines, the sensitive lines, and the distinctive lines. As one dilutes the amount of an element in an arc, the number of lines observable is reduced and ultimately there remain only a very few lines of the element which is diluted. These lines are thus known as the *raies ultimes* or persistent lines. Data have been collected for a large number of elements in a special table of persistent lines (Tables I, II and III). De Gramont indicated that the persistent lines are not necessarily the strongest lines in the spectrum, nor are they always the lines which require the least energy of excitation, i.e., the resonance lines. This statement has been shown to be incorrect, however, and recent studies by Meggers and Scribner (*C138*) based on more recent progress of spectral structures and correlation with electron configurations have enabled them to formulate rules governing a selection of these persistent lines. These rules may be summed up in the statement that a persistent line originates in a simple interchange of a single electron between an *s* and a *p* state, usually preferring configurations in which only one electron occurs in these states.

In many of the condensed tables which are available for spectroscopic examination the persistent lines are either listed separately or indicated with a prime (′) or letter (*p*) or (*P*), the most persistent lines being indicated by (*P*) and the next most persistent by (*p*). From their studies, Meggers and Scribner have shown that the persistent lines are also the lines of greatest intensity, and hence there are three ways of selecting these persistent lines: (1) by accurately measuring relative line intensities, (2) by observing the most persistent line as the element is diluted, and (3) by deductions from the theory of atomic spectra. Meggers has published (*C136*) a list of the strongest lines of the first and second spectra of chemical elements. These lines are the strongest of the persistent lines and result from a transmission between *s* and *p* electrons in the atoms (see Table I, page 400).

From this discussion on the persistent lines it is apparent that in the qualitative analysis for a certain element one need look only for the persistent lines of that element. If they are absent the assumption may be made that the element is not present in the sample.

QUALITATIVE ANALYSIS

The spectrum photograph may be obtained by direct arcking or sparking of a conducting sample or by the use of a carbon or other conducting electrode as a holder, and introducing the material on the electrode. If the instrument has a printable scale it should be recorded on the negative, and, on the other side of the spectrogram of the unknown, one should photograph a spectrum of a known element or compound, such as iron, copper, a known brass, "R-U" powder, or a sample of the principal constituent of the unknown (Fig. 4.7) (See Exercise 2, Chapter XII).

In the analysis of a brass sample (Fig. 4.8) the reproduction of a copper spectrum adjacent to a brass photograph enables the observer to mark at once all lines due to copper, assuming, of course, that the copper sample is spectroscopically pure. For routine analytical work the operator will have available negatives with the copper or other element lines identified so that the negatives may be compared simultaneously by projection or other methods. A convenient method of examination, especially if the dispersion of the instrument is low, is to make enlargements from 5 to 10 times the size of the original negative, mount the enlargement on a suitable card, and write in the lines as determined (see Fig. 12.4, page 298). For instruments which do not contain a graduated scale, and for more exact analysis, one may photograph an iron spectrum adjacent to the unknown. This in itself acts as a finely, though irregularly, graduated scale. Photographic charts indicating lines of elements in relation to iron (page 83 and Plates II to XXXVI) have been prepared for this purpose. Those which are included in this book (although one half the size common in analytical work) have been designed to enable the operator to use a strip enlargement of the spectrum or to project his spectrum in the blank space between the iron spectrum and the unknown lines. By experience it has been found that this method

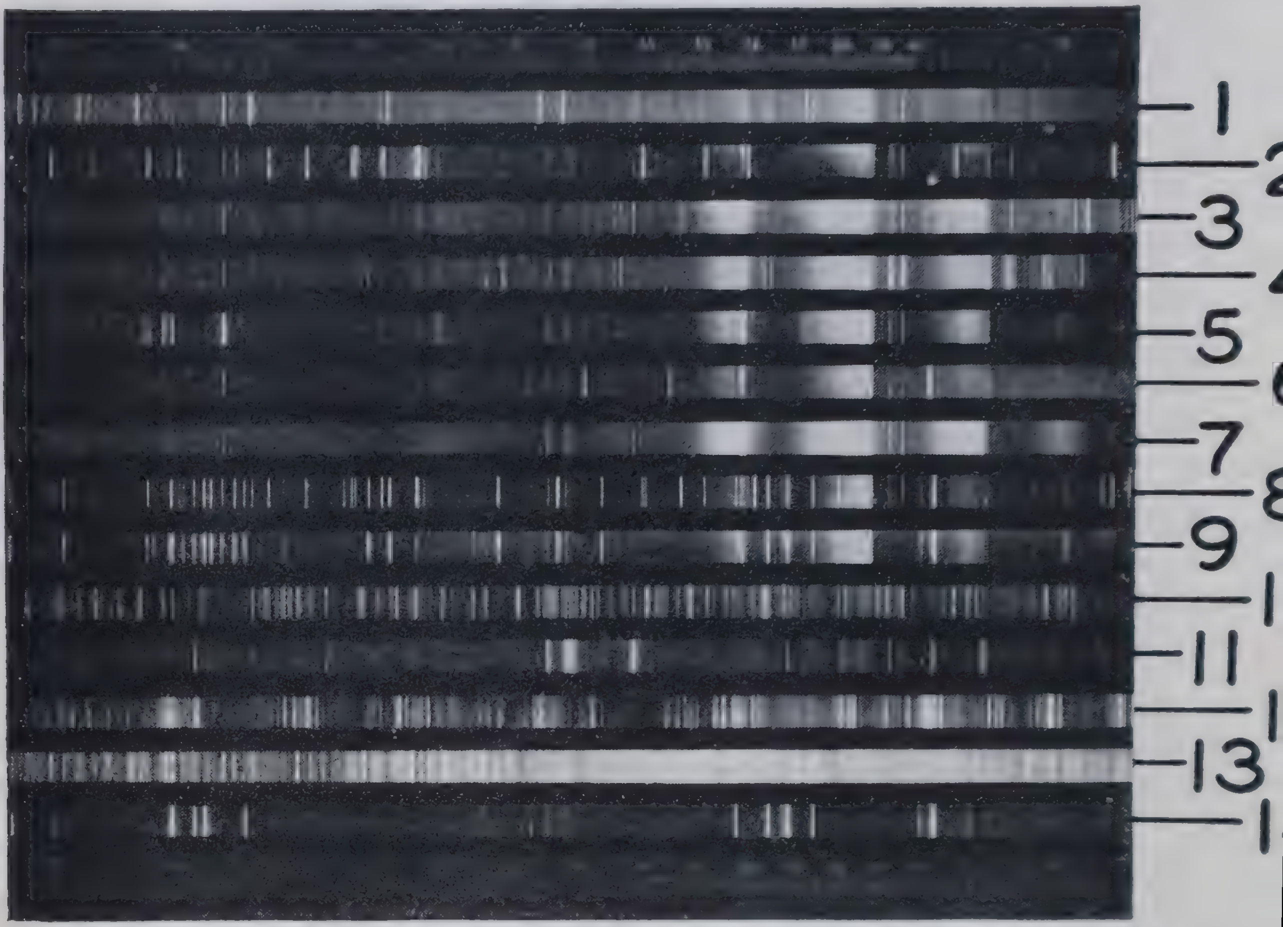


Fig. 4.7. Spectrograms of common materials. P.
1. C + Sb. 2. C + Bi. 3. C + Sr. 4. C + Ca. 5. C + Mg. 6. C + Na + K. 7. C.
8. Wood's metal. 9. Solder. 10. Pt. 11. Coin silver. 12. Mn. 13. Ce. 14. Pb.

is both rapid and accurate, and it is much more convenient to apply, especially to student instruction, than the microscopic examination of the original plate, if a large number of lines are to be identified (see section on photography, page 357).

The procedure of qualitative analysis may be roughly divided into two parts: (*a*) search for a definite element, and (*b*) identification of unknown elements. In the search for a definite element, the identification of the persistent lines should be sufficient to confirm the presence of the element, although in samples with a large number of lines the overlapping which may occur, especially with a low-dispersion instrument, may make these uncertain. At least three lines concerning which there is no possible doubt as to origin should be identified so as positively to identify the element.

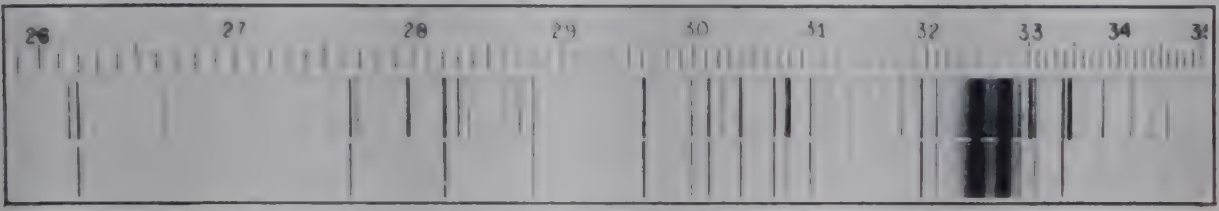


FIG. 4.8. Spectrograms of brass and copper samples. **N.**

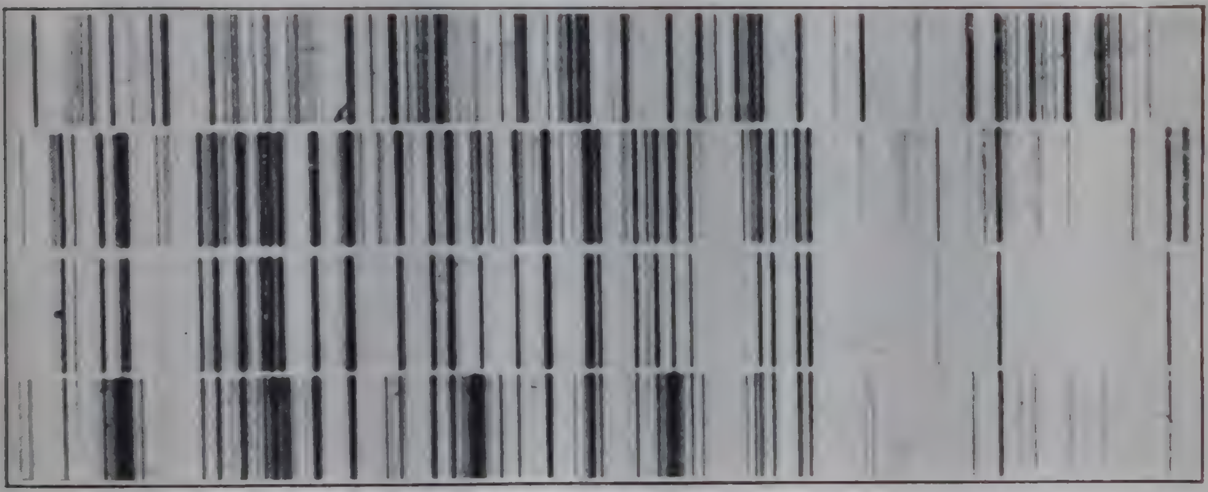


FIG. 4.9. Portion of spectrograms of nonferrous alloy (top), steel, iron, and steel (bottom). **N.** (A section contiguous to these spectrograms is shown in Fig. 12.15*a*).

The identification of unknown elements requires a more complete identification of all the spectral lines, except those which may be eliminated by means of a pure standard photograph and visual comparison It can be seen that in working with a nonferrous alloy unknown (Fig. 4.9) a pure-iron comparison spectrum would relieve the analyst of a great amount of measurement and identification work. A considerable amount of labor can also be avoided by the identification of strong lines of impurities not present in the comparison spectrum, and then, from th tables giving the lines of that element (Table VI), the remaining weake lines of the element may be rapidly identified and eliminated. It ma also happen that there are available in the laboratory photographs o pure samples of this impurity element so that direct comparison o photographs or prints may enable the analyst to eliminate a large grou of lines. For the remaining lines, and often this procedure may appl to the entire negative, the wavelength should be determined from th scale or comparison (iron) spectrum and the possible elements for eac line tabulated, consulting either photographic tables or, for more complete analysis, such tables as the Kayser "Hauptlinien" (*A56*), th Massachusetts Institute of Technology 100,000-line table (*A39*), th Scheibe table (*A81*), Twyman table (*A94*), or the table in this boo

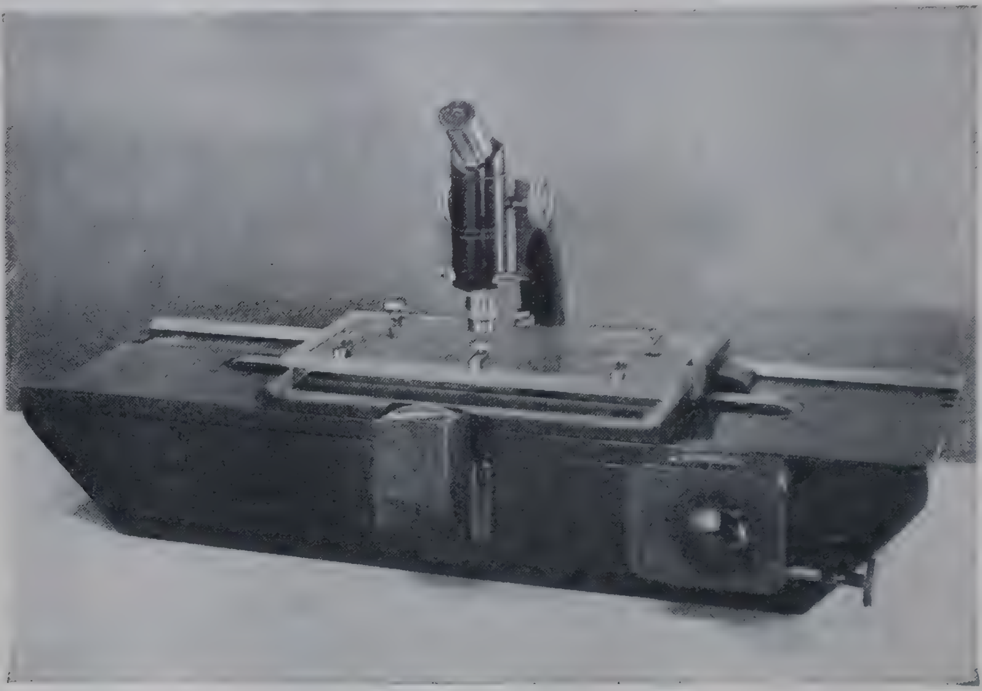


FIG. 4.10*a*. Spectrum comparator (Bausch and Lomb).

(Table V). Some of the available tables indicate the position of occurrence of the next strong line of the same element so as to enable th operator to make a rapid confirmation of the assigned element.

Line Identification

Experience will show that it is not possible by visual comparison o negatives from medium-dispersion instruments (2000 to 7000 A in 25 cm to assign the position of the line closer than one or two angstrom unit hence, as can be seen in Table V, there may be a number of possibilitie which can be eliminated in part by a search for the persistent lines o the elements which are possible. For very accurate analysis it may be necessary to determine the position of the unknown line more accurately. This may be accomplished by means of measuring devices such as a traveling microscope or micrometer eyepiece (Fig. 4.10). With grating instruments it is possible to make an interpolation measurement on the negative, between two or three known lines, and thus determine the wavelength. With prism instruments, in which there is a rapid change of dispersion with wavelength, a more complex formula (Hartmann formula) is used in which three known lines are required.

$$\lambda = \lambda_0 + \frac{c}{(n - n_0)^{1/a}}$$

where λ is the wavelength of the line in question; n, the index of refraction of the dispersing medium at the wavelength in question; and λ_0, c, n_0, and a are constants. For purposes of calculation the value of a may be assumed to be unity, and in place of the refractive indices one may use the micrometer readings on the plate for the unknown line s and the known line s_0. The equation then becomes

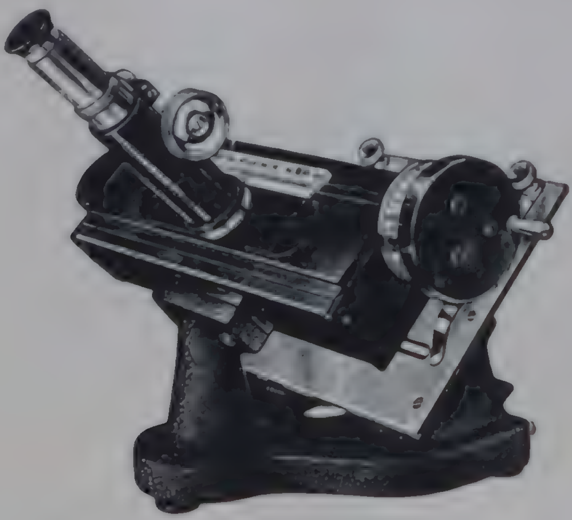


Fig. 4.10*b*. Spectrum comparator (Gaertner).

$$\lambda = \lambda_0 + \frac{c}{s + s_0}$$

which can be solved by measuring the micrometer values for the separation between the unknown line and three adjacent known lines (chosen so that not all are on the same side of the unknown line).

For all but the most exacting measurements it is possible to plot the known wavelength values against the micrometer readings and interpolate for the wavelength value of the unknown as determined by its micrometer reading. Over very limited spectral ranges, especially wi instruments of high dispersion, linear interpolation is sufficiently acc rate for the usual identification. For all grating work, even where tl system may be in the Eagle mounting or any other form which does n produce an exactly linear dispersion, direct linear interpolation is sati factory for element identification. One seldom uses the Hartman formula unless the assignment of wavelength to an unreported line the most exacting identification requirements are involved.

Standard Samples

For the purpose of superimposing, or printing in juxtaposition, spectrogram of a known standard substance, it is desirable to hav available special standard samples, similar to the analytical standard supplied by the Bureau of Standards for gravimetric analysis. Standar spectrographic samples are now available from the Bureau of Stand ards and a number of the large-scale commercial producers of high grade products as well as laboratory supply houses. Special mentio should be made of the Hilger samples of metals and salts which hav been prepared for spectroscopic standards. The Aluminum Company o America and the Dow Chemical Company have series of aluminum an magnesium alloys available for spectroscopic standards. A sub-com mittee of the American Society for Testing Materials committee o spectrographic analysis under the direction of T. A. Wright has pre pared a list of such samples for metallurgical identification (*D9*).

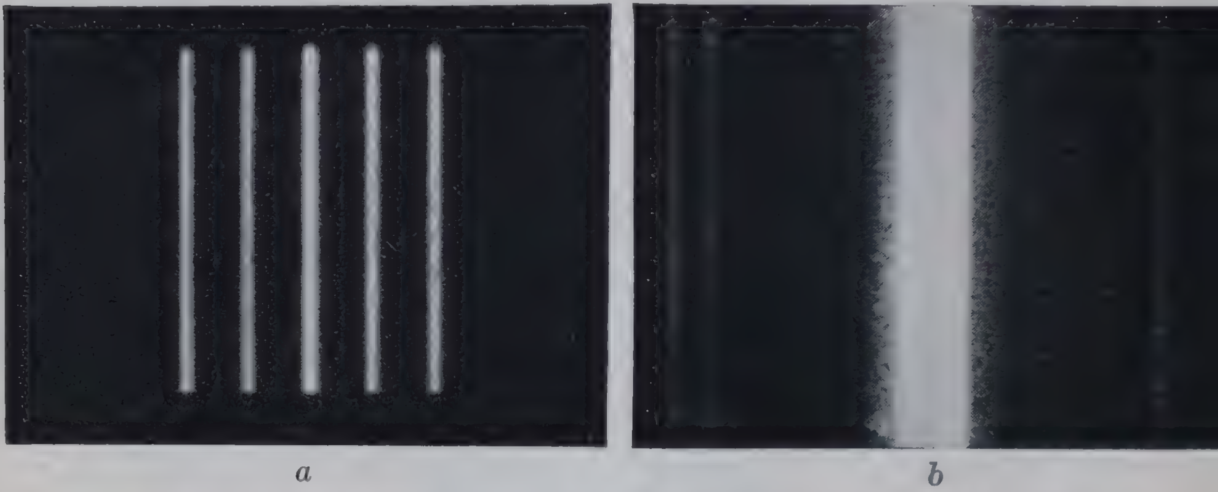


FIG. 4.11. Examples of spectrum line combinations for rapid identification.
a. Magnesium group of five symmetrically spaced lines at 2780 A. **P.**
b. Beryllium doublet at 3130.48 and 3131.13 A. Faint lines are ghosts from grating
(Crook.) **P.**

In the rapid qualitative analysis of a large number of samples on soon learns to recognize certain groups of lines so that one can identif their position on the negative in the absence of a scale, or confirm at once the presence of an element.

The extensive use of the iron spectrum as a calibrating scale makes it essential that the spectroscopist be able to identify separate sections of the iron spectrum. This is especially true if the negative is taken on a Littrow instrument in which only a portion of the spectrum appears on any one negative. For example, in the section at 3100 A, a strong triplet followed by four evenly spaced intense lines should be easily identified (Fig. 4.6). Another easily identified group is the double-single-double-single group at 2404-2413 A. The copper doublet at 3247–3274 A, and the magnesium group of five lines at 2776–2783 A (Fig. 4.11), are also very distinctive. A manganese group of three lines at 2794–2801 A, aluminum pairs at 3082–3092 and 3944–3961 A, and many other lines are easily recognized, and the experienced analyst should have little difficulty in identifying many elements by a superficial examination of the spectrogram.

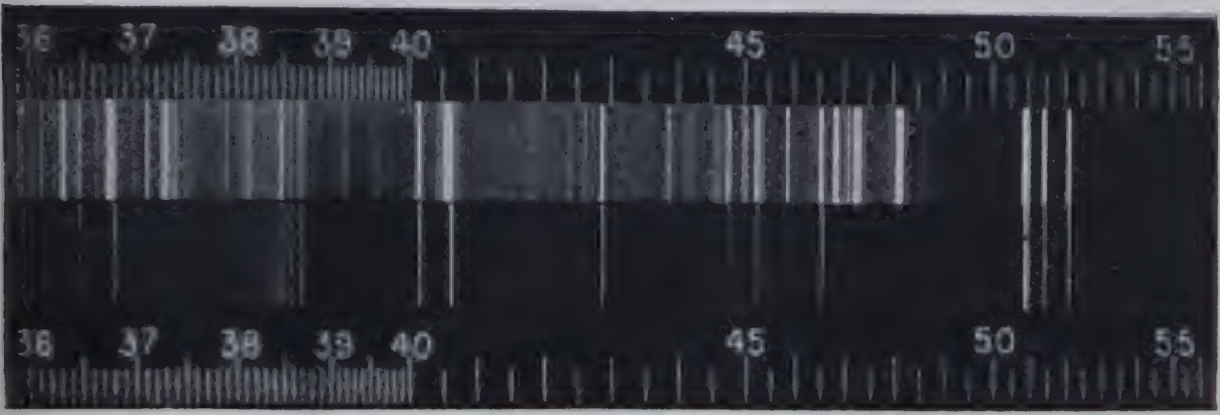


FIG. 4.12. Zinc group of three lines at 4680, 4722, and 4810 A and lead line at 4058 in a brass sample (upper spectrogram). Note characteristic copper group of three lines at 5105, 5153, and 5218 A and the pair of lines at 4022 and 4062 A. **P.**

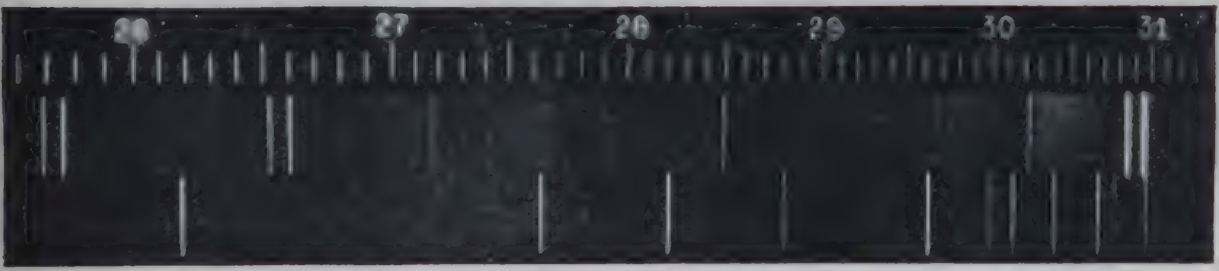


FIG. 4.13. Aluminum doublets (upper spectrogram) and copper comparison (lower spectrogram). **P.**

Heterogeneous Samples. If the sample to be examined is a heterogeneous material, such as a composite mixture of turnings from a large number of pieces, in which an average analysis is desired, it may be necessary to use a larger sample holder, such as a metal plate or cup, and to burn th arc for some time to obtain an average sample (*C28*). In such cases th light intensity can be reduced on the slit by means of a diaphragm at th focusing lens or by the entire elimination of a focusing lens between th arc and slit. In place of a diaphragm, absorbing wire screens or a rotatin sector (Fig. 3.20) may be used to allow greater sampling from the ar with a given photographic exposure. In most spectrographs, diaphragm are also provided at the lens (L_1) adjacent to the prism (focusing lens and these will have the same effect on the photographic intensity a diaphragming the slit lens.

LITERATURE

General

D. M. Smith, "Metallurgical Analysis by the Spectrograph" (*A85*).
S. Judd Lewis, "Spectroscopy in Science and Industry" (*A63*).
G. Scheibe, "Chemische Spectralanalyse" (*A81*).
F. Twyman, "The Spectrochemical Analysis of Metals and Alloys" (*A95*).

Reference

Gerlach (*A29*), Kayser (*A52*), Seith and Ruthardt (*A84*), Lowe (*B51*), Meggers (*C136*).
Spectrum tables listed on pages 78 to 82.

CHAPTER V

QUANTITATIVE EMISSION ANALYSIS

Development of Quantitative Methods

The early use of spectroscopic methods in the qualitative identification of elements naturally led to the consideration of quantitative determination by this same method. Lockyer (*C126*) (1873) was one of the first workers to propose the use of the spectroscope for quantitative analysis. His suggestion involved the determination of the length of the spark lines at each electrode as a measure of the concentration of the element. The classical publication of Hartley some ten years later in 1884 (*C102*) on the persistent lines of Mg, Zn, Cd, Al, In, Tl, Cu, Ag, Sn, Hg, Pb, Te, As, Sb, and Bi paved the way towards the field of quantitative analysis by indicating a correlation between element concentration and line intensity. Over twenty years later Pollok and Leonard continued Hartley's investigations by the publication of a series of seven papers on the spark spectra of a number of elements at low known concentrations, and a determination of the principal lines of elements in the spark spectra. Hartley, Pollok, and Leonard (*C122, C163*) used a solution system in which they indicated lines which were present in one concentration but not in concentrations of one tenth that amount, employing a definite sparking time and current density. The series used was as follows:

TABLE 5.1

Line Designations Used by Hartley (*C102*)

τ = lines present in the pure sample but not in a strong solution
σ = lines present in a strong solution but not in a 1.0% solution
ϕ = lines present in a 1.0% solution but not in a 0.1% solution
χ = lines present in a 0.1% solution but not in a 0.01% solution
ψ = lines present in a 0.01% solution but not in a 0.001% solution
ω = lines present in a 0.001% solution but not in a 0.0001% solution

De Gramont (*C66, C67*) published a number of papers during the first quarter of the present century, most of which deal with the persistent or *raies ultimes* lines and their application to spectrum analysis. In 1920 he published his table of persistent lines also known as sensitive lines, principal lines (*raies ultimes*, or *letzten Linien*) (see Tables I, II, and III in Appendix), which was an important contribution to both qualitative and quantitative analysis. In this table of persistent lines, de Gramont indicated the *raies sensibles* and *raies ultimes* as the persistent lines in the visible and ultraviolet regions respectively. The term *raies ultimes* has since been applied to persistent lines in both these spectral regions (*C136*).

Work of Meggers, Gerlach, and Scheibe

Meggers, Kiess, and Stimson published in 1922 (*C137*) a series of quantitative spectrographic determinations on samples of tin, gold, and platinum, using the methods which de Gramont originated in 1895. For a quarter of a century, de Gramont had been almost the sole proponent of this analytical procedure. In this paper by Meggers and his co-workers, alloys of known concentration were used as standards, such as a platinum series containing the following rhodium concentrations: 1.0, 0.5, 0.01, and 0.001 per cent. The unknown sample of platinum was sparked in a condensed spark in accordance with the de Gramont method, and the spectrogram obtained was compared with spectrograms obtained under similar sparking conditions from the known standards. The density of the persistent lines or *raies ultimes* served as a measure of the amount of rhodium in the unknown sample. Similar standards and density determinations were made on a series of gold samples containing from 1 to 0.001 per cent of silver, copper, iron, and lead. In the analysis of fusible plugs of tin it was shown that one might expect such impurities as lead, zinc, antimony, copper, iron, arsenic, and bismuth. A comparison of the results obtained by spectrographic and chemical means (Table 5.2) demon-

TABLE 5.2

Comparison of Spectrographic and Chemical Analysis of Tin Alloys (*C137*)

Sample	%—Spectrographic							%—Chemical			
	Cu	Pb	Fe	Zn	Ni	Ag	Bi	Cu	Pb	Fe	Zn
3993	0.1	0.1	0.005	0.001	0.001	0.000	0.000	0.08	0.10	0.03	
4409	0.6	0.05	0.1	0.07	0.001	0.000	0.000	0.62	0.04	0.04	0.06
4148	0.4	0.08	0.07	0.005	0.001	0.000	0.001	0.45	0.10	0.09	
4199	0.8	0.6	0.02	0.04	0.01	0.001	0.01	0.76	0.63	0.02	
4247	0.6	1.0	0.01	0.15	0.01	0.001	0.01	0.65	0.98	0.042	

strated that this new method was capable of giving quantitative results with considerable precision. "In fact, the precision probably surpasses that of the chemical gravimetric method in a case of this kind, for it is precisely for the small quantities for which weighing errors are large that the spectral methods show their greatest sensitiveness. The greatest economy, however, is in materials and time. Whereas a chemical analysis will require about 10 g. of material, only a few milligrams are consumed to make a spark spectrum. A dozen samples carried along simultaneously require about two days for a chemical analysis. The same can be accomplished in two hours by the spectral method" (Meggers, Kiess, and Stimson) (*C137*).

The actual determination of line intensity was made by a visual comparison of the unknown-sample persistent line with the series of photographs of the known-sample persistent line. This measurement of comparative density of two lines can, of course, be made visually or by some mechanical or electrical means. Much of the improvement that has been made in the spectrographic quantitative methods, since the pioneering work of Meggers, has been in the direction of increased accuracy in measurement of line intensity or density.

PHOTOGRAPHIC MEASUREMENT OF LIGHT INTENSITY (*A23*)

Line intensity may be measured in a number of ways, nearly all of which are photographic. The photographic emulsion produces a blackening on the developed negative which is not directly proportional to the light intensity affecting the silver halide but, as can be seen from the $d/\log I$ curve (Fig. 5.1), is, for a considerable intensity range, a linear function of the log of intensity. (See Chapter XIII, "Theory and Practice of Photography.") This linear range provides a means of interpolation between known light concentration or intensity values, provided, of course, that the conditions of exposure are so regulated that the density of the line in question falls within the limits of this linear slope.

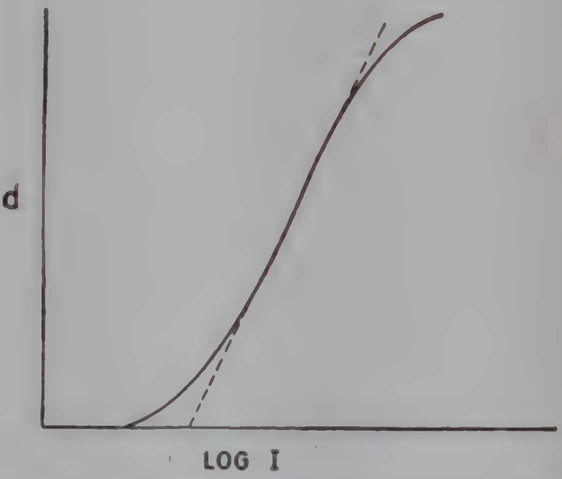


FIG. 5.1. Variation of density (d) with light intensity (I) of a photographic emulsion.

Two sources of error should be considered when using the photographic method of intensity comparison. In the first place there is what is known as the reciprocity failure, which may be expressed as the failure of photographic emulsions to conform to the relation

$$\log I \cdot t = \mathrm{d} \quad (\text{where } \log I \cdot t = \text{a constant})$$

where I = intensity, t = time of exposure, and d = density of the image formed (see Fig. 13.6). It can be shown that there is an optimum exposure time, requiring a minimum light intensity for unit density, and an optimum light intensity, requiring a minimum exposure time, for a given emulsion. For intensity or time values differing from this optimum value, a greater value of $I \cdot t$ will be required to produce the same unit density.

The second possible source of error, which results from the reciprocity failure and the inertia of the photographic process, is known as the intermittency effect. If an exposure of 100 seconds with a given source is required to produce a unit density of photographic image, then ten separate exposures of 10 seconds each should produce the same density. The failure to obtain the same density is known as the intermittency effect. It has been shown, however, that if the number of interruptions (sector revolutions) is greater than about 20 per second or the total number of interruptions in an exposure is greater than 50 there is no great intermittency effect and the errors from both these sources will, in their application to quantitative spectrographic analysis, be less than the usual errors in observation.

Except where observations are made on lines of approximately the same density, it is essential that the photographic negative be calibrated, i.e., that the $d/\log I$ curve (see Fig. 5.1) must be determined for the particular wavelength and emulsion used. Such a calibration can be most easily accomplished by means of a rotating step sector in front of the slit of the spectrograph (see Fig. 5.5).

INTERNAL STANDARDS

The uncertainty with regard to the relation between density and logarithm of intensity may be eliminated if the element line in the unknown can be compared with the same line in a series of samples with known varying concentration and in which one of these series gives the same line density as the unknown sample. It is obviously impossible to incorporate within the unknown sample a definite amount of the known material for which the test is being made. To accomplish this comparison, it becomes necessary to refer the intensities of the lines in the known and unknown samples to some common line of an extraneous element which remains unchanged in both spectra. This method of "internal standard" control was first developed by Gerlach (*A30*). Two types of internal standard lines may be used: (*a*) a weak line of the element which is the major constituent of the sample, which line is known to be constant in intensity, within the limits of experimental observation; and (*b*) a strong or persistent line in the spectra of an added small amount of an element which is known not to be present in either the known or unknown sample. The observed lines can then be classified in pairs of equal intensity, i.e., known or internal standard line, and unknown line. The preparation of a series of standard samples with a varying concentration range of the "unknown" element and observation of the spectra of these samples provide data for the selection of a series of these pairs to cover any desired concentration range. Since both the unknown and the internal standard are a part of the same sample, it is obvious that variation in the time of exposure, plate characteristics, or developing conditions will not affect the relative density of two lines which are equal in intensity in the light source.

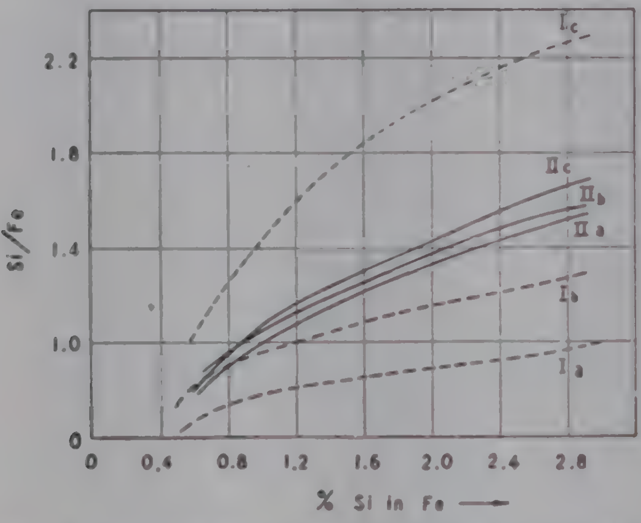


FIG. 5.2. Comparison of working curves from lines representing similar excitation response (I) and different response (II) (Scheibe [*C178*]).

One condition which will influence the relative intensity of a pair of such lines will be a variation in the excitation conditions of the arc or spark, if the two lines are chosen so as to represent markedly different energy conditions in the arc or spark. For example, one line may be due to a singly ionized atom of low potential of excitation and the other to a doubly ionized atom which requires a high ionization potential (Fig. 5.2). An increase in the temperature or voltage would favor the latter line and reduce the intensity of the former. For further control and as a means of increasing the accuracy of the observations, definite arc or spark conditions are maintained, and, in addition, one may define the conditions spectrographically, i.e., choose a pair of lines, representing low and high excitation conditions of the same atom, which are equal in intensity under the prevailing spark or arc conditions. This condition o spectral character may then be added to the internal standard pai equality as a guide to a fixed concentration ratio of known and unknown lines (Table 5.3).

Homologous Pairs

A second method of avoiding the possibility of error due to a change of arc or spark conditions is to choose for the known internal standard line and the unknown comparison line, which are to be of equal intensity for a given concentration, lines which are known to have approximately the same excitation conditions so that within a considerable change in arc or spark condition any change which may take place in one line intensity will also take place to the same extent in the other. Such a pair of lines has been defined as an "homologous pair" (*A28*, *A29*). The choice of homologous pairs of lines for spectral analysis may be made by a study of known standards under varied conditions of arc or spark (variation of voltage, inductance, capacity, etc.), and once these pairs have been established it becomes possible to eliminate some of the errors involved in earlier quantitative analyses. For more exact determination of homologous pairs one may, of course, revert to the spectral analysis of the individual elements, determining the term, levels, multiplicities, etc., and may choose from similar conditions the lines to be compared.

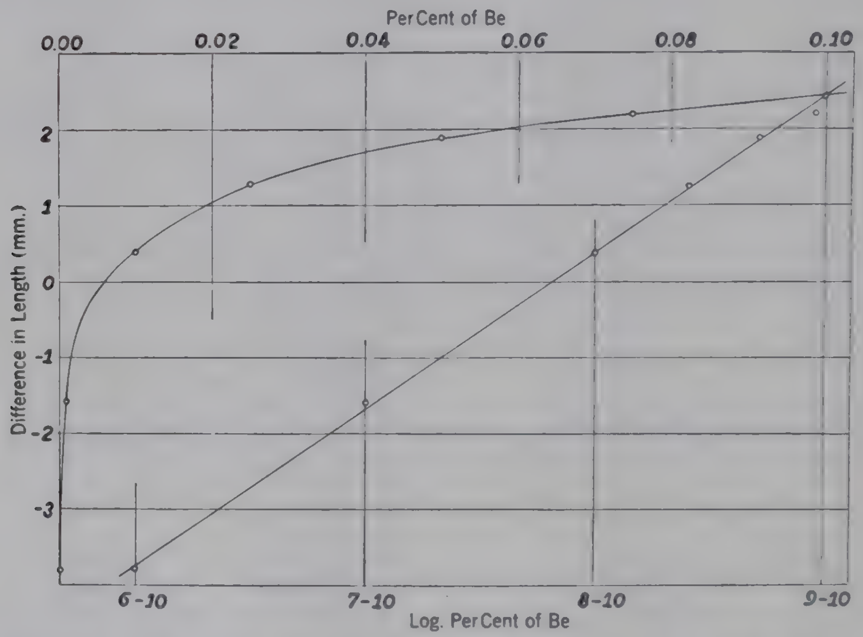


FIG. 5.3. Working curve for determination of beryllium (3132.3 A). Bismuth internal standard (3067.7 A). Brode and Steed [*C52*].)

A pair of lines which does not respond with equal intensity change when the excitation conditions are changed (such as lines due to different ionization stages) may be chosen as "fixation pairs." Such fixation or control pairs are useful in specifying excitation conditions; for example, in Table 5.3 the excitation conditions are defined as those in which the Sn II line of 3352 is equal in intensity to the Sn I line of 3330 A.

The use of homologous pairs removes the necessity of accurate control of the excitation conditions although reasonable control should be practiced in spectrographic analysis. If it were possible to control the excitation conditions accurately as might be indicated by a very sensitive control pair a much wider choice of analysis pairs would be available, but in most cases sufficient homologous line pairs are known so that this extra control is not essential.

TABLE 5.3

Homologous Pairs and Control Standards for Analysis of Bismuth in Lead

(Gerlach and Schweitzer) (*A30*)

Excitation control pair
Sn II 3352.3 = Sn I 3330.6 A

Pb		Bi	%Bi
2657.1	=	2730.5	5
2657.1	=	2780.5	1.5
3220.5	=	3024.6	1.5
3220.5	=	3067.7	0.07

Having chosen an homologous pair of lines which are known to be of equal intensity for a definite concentration ratio, regardless of the excitation conditions within the experimental limits of variation, or a fixation pair of lines which are known to be of equal intensity for a definite concentration ratio, at a definite excitation condition which can be controlled, one is confronted with the possibility of variation of the "unknown" concentration. Since the photographic negative, over an appreciable range, has a linear relation between the negative density and the logarithm of the light intensity, and since the amount of the element and the intensity are, by definition of method and control, concomitant, one may measure the relative density of the known and unknown lines and thus may construct a working curve for the element over a considerable concentration range of the unknown. Thus the determination is not limited to a series of definite concentrations by the equal intensity method. In the graphical representation of a working curve (Fig. 5.3) one may plot the logarithm of the concentration of the unknown against the ratio of the densities (which is a linear function of the logarithm of the concentration or light intensity), and in such a case one should obtain a straight line over the concentration range within which the method is applicable.

LOGARITHMIC SECTOR METHOD

Scheibe presented a fundamental contribution to the practice of quantitative spectroscopic analysis when he introduced the use of a logarithmic sector in front of the spectrograph slit (*C178*, *C179*). The use of step or linear sectors or filters in front of a spectrograph slit as a means of measuring intensities was not original at the time, but this was the first application to quantitative analysis. Hamburger and Holst (*C94*) had previously used a logarithmic sector in front of a spectrograph slit for the determination of intensity ratios in multiplets. The sector may be cut either in a smooth curve, which is equivalent to an infinite number

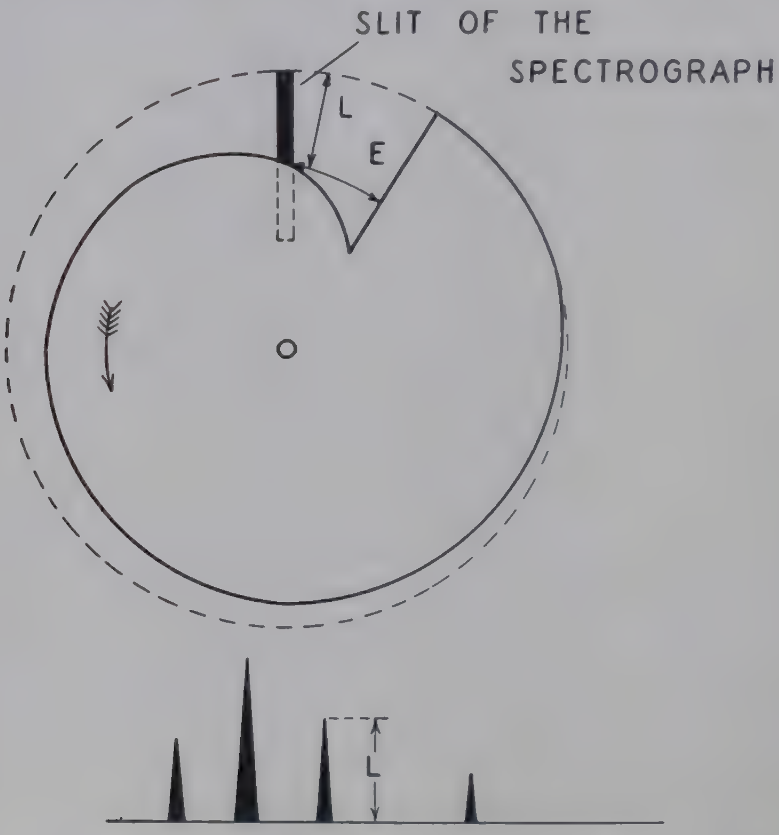


FIG. 5.4. Logarithmic sector (appearance of spectrum lines of different intensity indicated below).

of steps (Fig. 5.4), or in a finite number of steps (Fig. 5.5). The step sector limits the measurements to certain density levels but, in turn, permits the application of density photometers to the measurement of the blackening of the photographic plate. Neutral wedges may also serve the same purpose as rotating sectors, and these may be either of continuous or stepwise gradation. Partially silvered mirrors are not suitable on account of the ultraviolet transmission of silver films, but the evaporated aluminum, antimony, or sputtered-platinum mirrors are quite satisfactory for this purpose. Since within certain limits the width of the spectrum line produced from a uniform light source projected on the slit remains constant, but the photographic density increases as one increases the slit width, one may use a step or sloping slit in place of a step sector in front of the slit. Such a slit is difficult to operate since it must be kept at a definite width in order that the step ratios will bear the proper relation to each other. Vierordt (*C200*) has designed a special two-step slit of this type, involving two separate jaws operating against a common jaw so that the slit widths could be set to any desired ratio. Hansen (*C95*), Scheffer, and Duffendack and Wolfe (*C74*) have proposed step slits with more than two steps but lacking the ability of adjustment of the ratio between step widths. Such a series of slit widths can best be

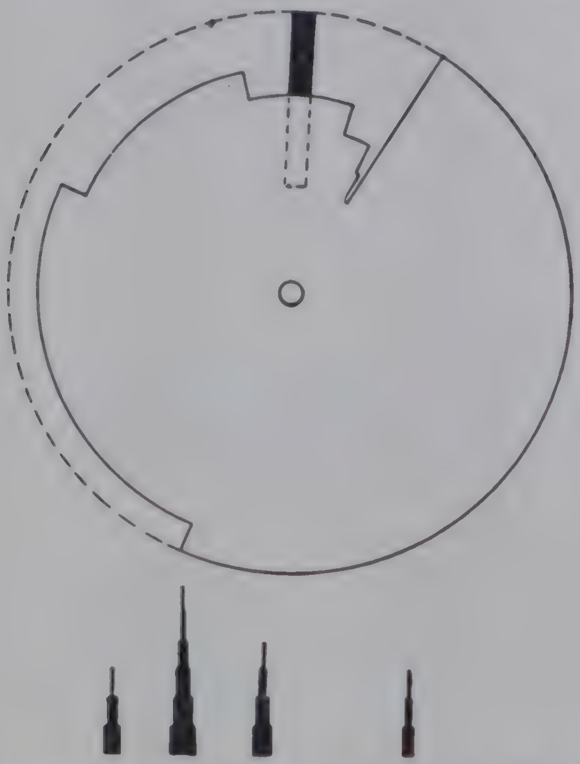


FIG. 5.5. Step sector (appearance of spectrum lines of different intensity indicated below)

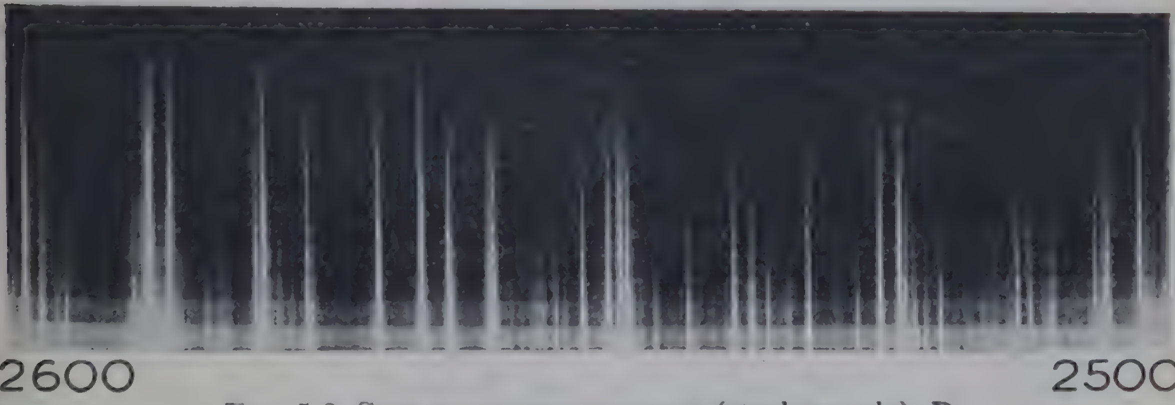


FIG. 5.6. Step sector spectrogram (steel sample). P.

produced by ruling a series of superimposed lines on a metallized quartz plate, each line in the series being shorter by a definite amount and broader by a definite amount compared with the preceding line so as to produce approximately a logarithmic difference in the light transmission. The actual width of the lines is not of extreme importance since the slit can be calibrated against standard density wedges (Fig. 3.19).

In the application to grating instruments where the nature of the mounting prevents the use of a sector or wedge at the slit, one may place such a device at the focal point of the grating or immediately in front of the negative. With the second arrangement it is necessary to have a cylindrical rotor so as to reduce equally the intensity of all lines on the plate. Such a rotor, usually a hemicylindrical segment of a solid cylinder, may also be placed in front of a quartz spectrograph slit, where it will produce a double set of tapered lines.

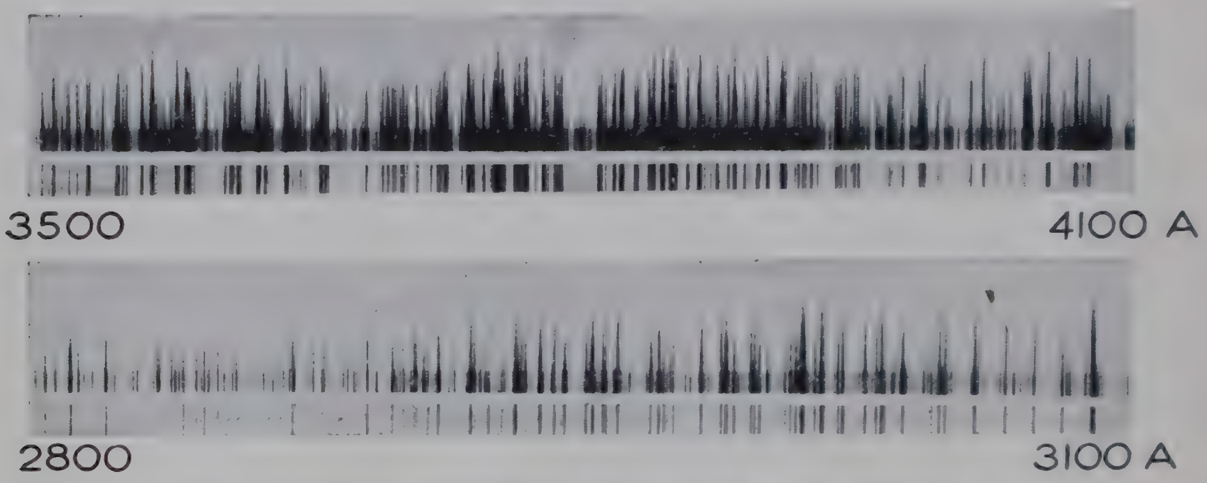


FIG. 5.7*a*. Logarithmic sector spectrogram (steel sample). **N.**

All these step or gradient sectors, slits, and density wedges produce the same type of effect on the photographic plate, namely, a spectrum line of graded density, the degree or character of the density change being dependent on the type of the device. Step sectors, step slits, and step wedges produce lines with a definite series of density steps (Fig. 5.6), whereas smooth sectors, wedges, and slits, which are the equivalent of an infinite number of steps, produce a gradual density change in the line. While all types of these reducing devices can be calibrated in terms of relative density per step or height of line from a given base, it has been found extremely convenient to cut or make the gradient device with a logarithmic extinction factor. For a step or smooth sector, this can be done by use of a logarithmic curve or steps in preparation of the sector.

An important prerequisite of the gradient line method (the use of a logarithmic sector, step slit, density wedge, or rotor in front of the negative) is that the slit should be uniformly illuminated along its entire effective length. The use of a lens system which projects an image of the arc or spark on the slit is obviously unsatisfactory since the line density varies within an arc or spark unless only a very small portion from the center of the arc or spark can be used and projected with a long-focus lens to furnish a rather large image on the slit. A method quite often employed with considerable success is to place a lens as near as possible to the slit and sector. This lens should be of such a focal length as to focus the light source on the collimating lens of the prism. In order to eliminate electrode ends or other parts of the arc or spark, a suitable diaphragm can be inserted at this point (Fig. 5.8). Other suggested methods include substituting a cylindrical condensing lens for a spherical lens for illumination of the slit; the omission of the condensing lens; and focusing the light source on a diaphragm so as to select the center portion of the arc or spark, and then projection of this illuminated diaphragm on the slit in a sufficiently large image to approximate parallel light.

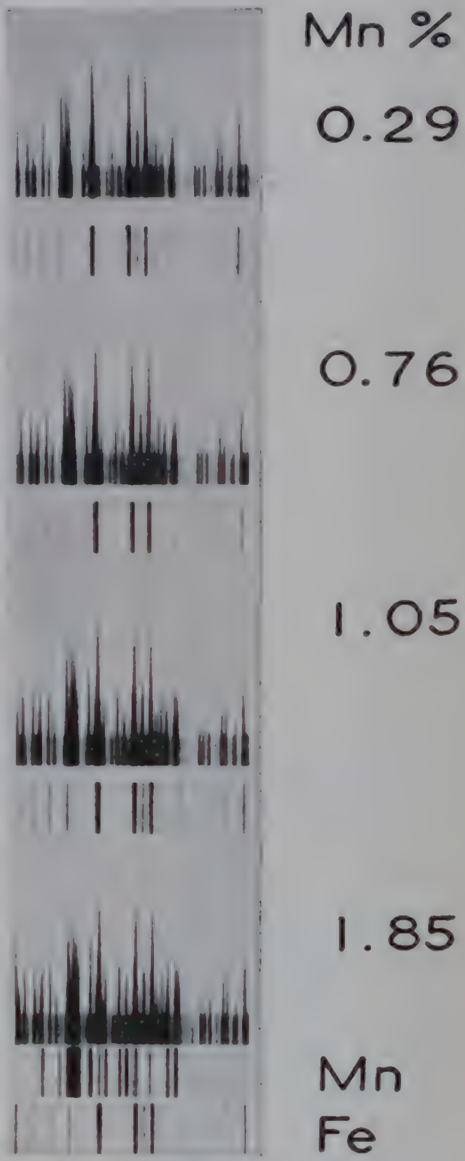


FIG. 5.7*b*. Logarithmic sector spectrogram (steel sample). N.

The logarithmic wedge or sector reduces the intensity of the light passing through the slit, and, assuming that the photographic plate is capable of integrating intermittent exposures so as to compare exposures of shorter time and greater intensity with longer time and weaker intensity, an equal blackening of the photographic plate will be produced at points along the graded spectrum line where the light intensity is the same. The measurement of density is effected through a measurement of the length of the graded line. The intensity of two lines at the pointed end will be the same, and, if the relative exposure has been produced by a logarithmic device, then the length of the line from a given reference point will be a logarithmic function of the intensity of the line in the source (*C196*).

As has been pointed out, the more nearly the control and unknown lines approach to equal intensity, the more accurate can be the determination of relative intensity and the less will be the influence of plate

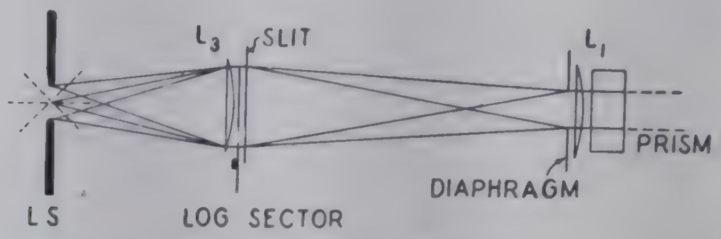


FIG. 5.8. Optical arrangement for use of logarithmic sector or diaphragm at the slit.

characteristics. As a means of bringing control and unknown lines to approximately the same intensity, where available lines of control and unknown lines can be found of approximately equal intensity, a method has been suggested for the use of a plate filter to reduce the intensity of one of these lines to nearly that of the other (see page 49). A balancing of relative line intensities of unknown and internal standard lines

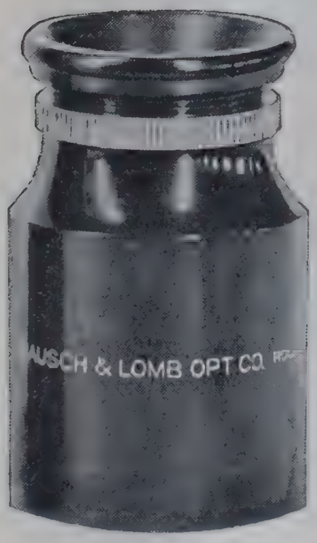


FIG. 5.9a.

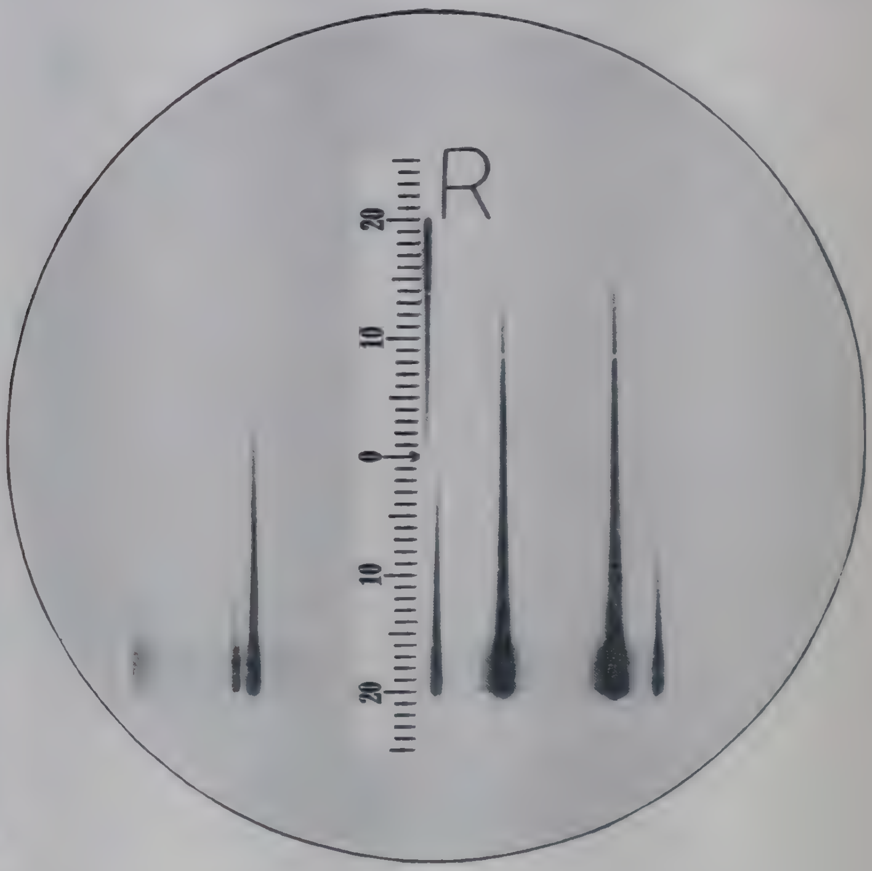


FIG. 5.9b.

FIG. 5.9a. Spectrum measuring magnifier (Bausch and Lomb).
FIG. 5.9b. Special eyepiece for line density matching. Inverted comparison line and scale are part of the field of the reading glass. (Wilhelm [C204].)

permits the use of a logarithmic sector of smaller pitch and hence greater accuracy over a more limited concentration range of the unknown.

Line intensity can be determined by means of logarithmic sector methods, by a direct measurement of the length of the spectrum line, and the ratio of two line intensities by the difference in their lengths. Since the ratios of intensities are the data which are used in quantitative analysis, the length may be measured from any point common to both lines, such as a streak on the spectrum lines due to a dust spot or irregularity in the slit, or from the mark caused by the outer edge of the rotating sector. The measurement may be made with a microscope with a measuring eyepiece or a simple reading glass with a built-in scale. Such an instrument is available from the Bausch and Lomb Company in which the scale is divided into tenths of a millimeter and with which the length of a line can be estimated to about 0.02 mm (Fig. 5.9a). As another method of measurement, the negative can be enlarged either by projection or photographic enlargement and the length of line measured with a millimeter ruler.

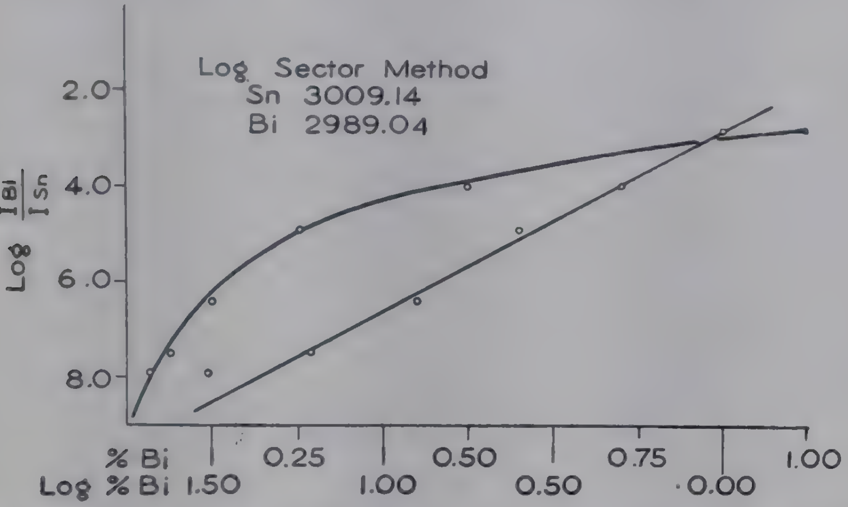


FIG. 5.10. Working curve for analysis of bismuth, logarithmic sector method.

In the comparison of two lines such as an internal standard and an unknown line, the length of each line will be a measure of its intensity and the logarithm of the ratio of the intensities can be expressed as log I_s − log I_u. With a logarithmic sector each line becomes a logarithmic intensity measure and the difference in length of the lines expresses the intensity ratio. This difference, as can be observed by experiment, remains the same for various conditions of exposure, slit width, development, and plate characteristics, as long as the sector or wedge gradient is sufficient to include the transmission or opacity values required to produce the same selected density in both lines. It is not necessary to use the point of extinction for matching, and a method has been suggested (Fig. 5.9*b*) in which a reverse graded line or pair of lines has bee used in the micrometer or measuring eyepiece and the density for matching chosen for some finite value (*C204*).

DENSITOMETER METHOD (*A89*, *C149*, *C113*, *C14*, *C156*, and *C162*)

In the above-described gradient density logarithmic sector methods it is not necessary to consider the plate characteristics, exposure time, amount of current interruptions, development time, or many other disturbing factors. However, if these factors are carefully controlled, one may improve on the accuracy of the gradient method by the use of a densitometer method. In this controlled method one may compare exposures of the unknown sample with similar exposures of a series of known samples and match to an equivalent density (the method used by Meggers *C137*) in his first reported quantitative analyses).

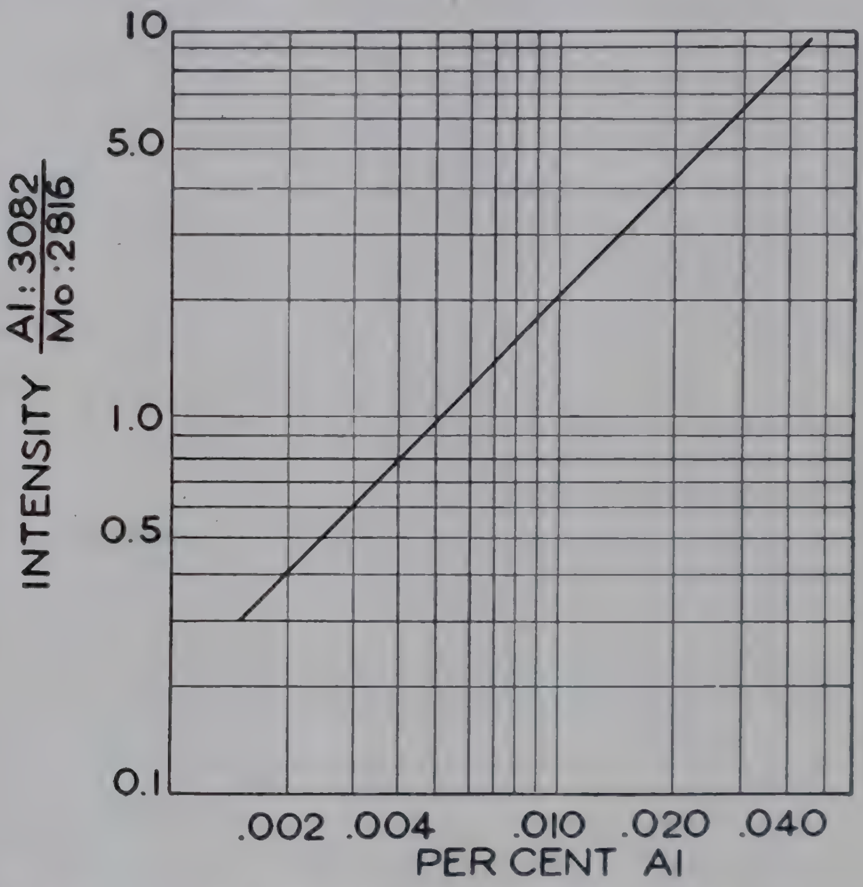


FIG. 5.11. Working curve for determination of aluminum with molybdenum as an internal standard. (Pierce [*C162a*].)

If both the internal standard and unknown lines are found to be of equal intensity, no additional calibration of the plate is necessary. With the step sector, or other step gradient device, it is possible to use a photometer to measure mechanically the density of the chosen line pairs.

From the known transmission values of the various steps it is a simple matter to determine the transmission for the steps giving a uniform density of the internal standard and unknown spectrum lines, and the ratio of these logarithmic step or transmission values, as in the case of the smooth logarithmic wedge or sector, will give an indication of the amount of unknown in the arc or spark. In view of the linear nature of the $d/\log I$ curves and the comparison of the two lines at the same blackening or density value, it is possible to set up a curve which will indicate the ratio of intensity of the two lines (known and unknown) over a considerable concentration range. This curve, known as a working curve (Figs. 5.11 and 5.20), forms the basis for rapid and exact quantitative analysis. If one plots the logarithm of the percentage concentration rather than percentage concentration itself, a straight line will be obtained over that particular concentration range in which extraneous factors do not interfere with the analysis.

In the analysis of a number of samples for the same unknowns, the controlled conditions of exposure should yield internal standard lines of uniform density which may serve as a check on the constancy of exposure conditions. The series of unknown lines can thus be compared directly with a series of lines from standard samples of known composition which should be recorded on the same negative.

The change in density of the lines of the unknown can be shown to bear a nearly linear relation with logarithms of the concentration of the unknown. Hence, by the use of an internal standard of unit concentration, the difference of the density of known and standard lines should give a linear relation with the logarithm of the concentration of the unknown.

In the simplest case, in which the plate characteristics and photocell response may be assumed to be uniform, the density difference Δd may be indicated as

$$\Delta d = \log \frac{D_1}{D_2} = \log D_1 - \log D_2$$
$$= d_1 - d_2$$

where D_1 or D_2 are the galvanometer deflections for the known or standard (D_1) and unknown (D_2) lines, and $\log D_1$ and $\log D_2$ are the densities (d_1 and d_2) of the lines. The galvanometer deflections (D) are measured as the swing from the zero or clear deflection value (*C14*, *C85*, *C149*, *C162a*, *C190*, *A104* and *A89*).

The plotting of Δd values for a series of prepared "standard" samples of the unknown against the concentration or log concentration of the "unknown" provides a working curve in its simplest form (i.e., withou plate or other calibration corrections).

The amount of unknown element present in an analytical sample i determined by measuring the galvanometer deflection for the unknown and internal standard lines, obtaining the logarithm of the ratio, and from the working curve ascertaining the concentration equivalent to the calculated line intensity ratio value (Δd).

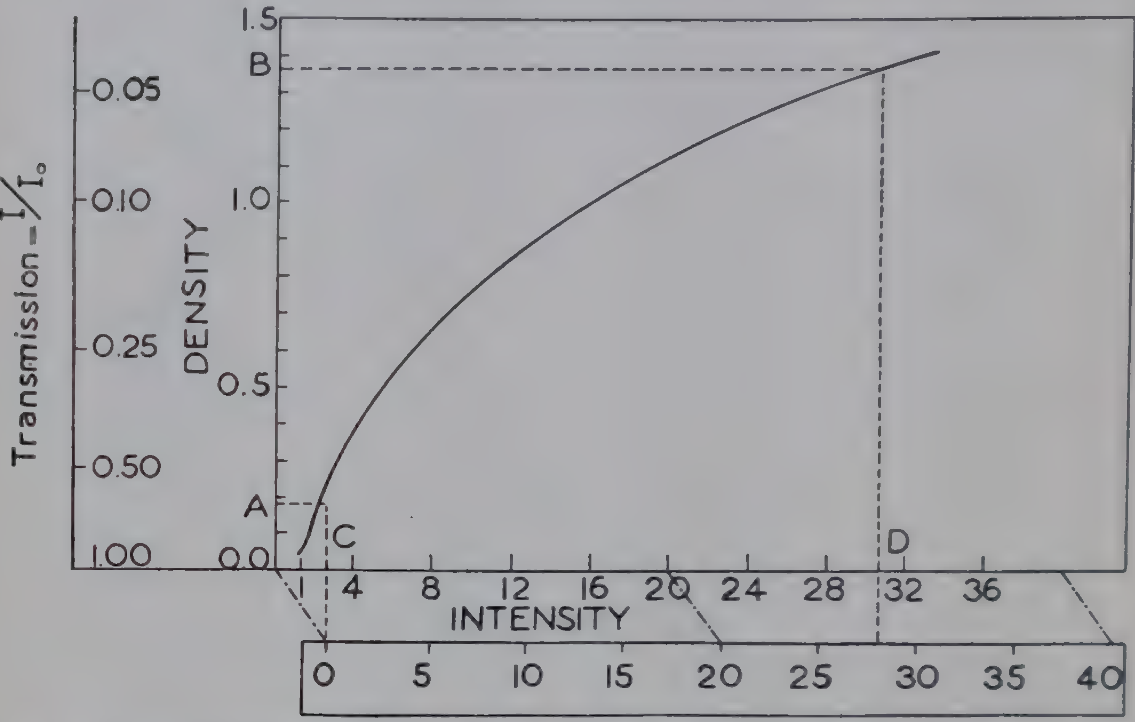


FIG. 5.12. *d/I (Density/Intensity)* curve used for background correction and plate calibration. (Pierce [*C162a*].)

Background density (A) corresponds to intensity (C) and line density (B) corresponds to intensity (D). Corrected line intensity (B–C) is obtained by offsetting the linear intensity scale by the amount (C). The deflection ratio (D/D_0) becomes intensity ratio (I/I_0) if the galvanometer deflection shows a linear intensity response. The per cent transmission becomes the linear galvanometer deflection (D) if the clear deflection (D) is set to 100. For other clear deflection values the per cent transmission becomes $I/I_0 \times 100$ or $D/D_0 \times 100$.

Pierce and Nachtrieb in a paper entitled "Photometry in Spectrochemical Analysis" (*C162a*) have carefully considered the factors influencing spectrochemical data as determined by the densitometer methods. The density (d) of a given spectrum line may be expressed as

$$d = \log_{10} \frac{I_0}{I} = \log_{10} \frac{1}{T}$$

when

$$T \text{ (transmission)} = \frac{I}{I_0}$$

where I_0 = *incident light* and I = *transmitted light intensity* (incident light may be considered as the light transmitted by a clear portion of the plate) and T = *transmission*. If the total deflection for the clear plate can be adjusted to a scale value of 100, then the spectrum line deflection becomes the transmission × 100, and, since the density of the line is equivalent to the logarithm of the reciprocal of the transmission, these deflection values (or deflection ratios if the total clear deflection is not set to 100) can be plotted on a log-reciprocal-scale so as to obtain density values (Fig. 5.12). The conversion of line density to intensity values is made by a $d/\log I$ or a d/I curve (Figs. 5.12 and 5.13). If background correction is to be made, the latter type of conversion will be required or antilog values obtained from the $d/\log I$ curve. (See sections in this chapter on *background correction* and *plate calibration.*) The calibration curve is in itself determined from line density values, and if this is in turn used to determine background correction it must be assumed that the calibration spectra are free from background effect. Such calibration spectra must therefore be obtained from spectrograms free from background or the calibration curve must be assumed to include background correction and in such cases the ana-

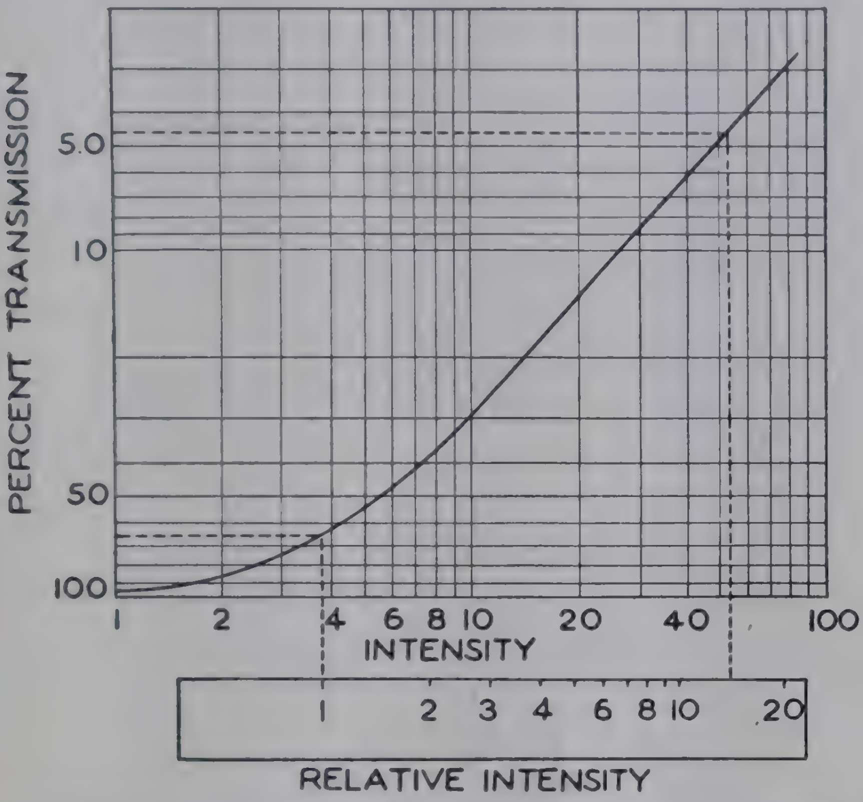


FIG. 5.13. Curve for calculation of relative line intensity. The use of log-log paper permits the direct plotting of photometer readings without conversion to density values. (Pierce [*C162a*].)

lytical data used must be observed under the same conditions as thos under which the calibration data were obtained.

Plate Calibration

The calibration of spectrum negatives, which is unnecessary in th logarithmic sector method, is essential to obtaining the highest accurac in the line density methods. The purpose of plate calibration is to determine the $d/\log I$ or H. and D. curve in order that density of th photographic image may be related to the intensity of the light producing the image.

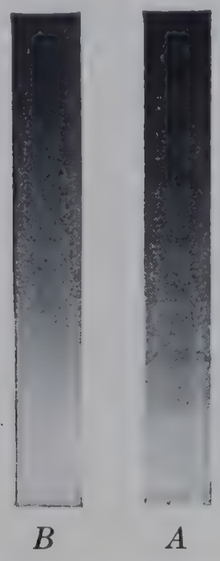


Fig. 5.14*a*. Step density wedge (*A*). Log density wedge (*B*).

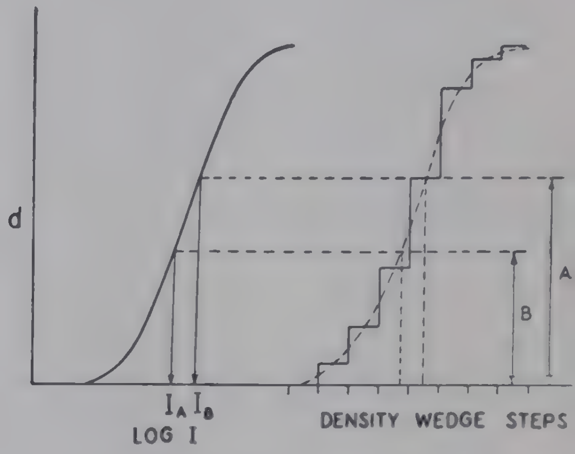


Fig. 5.14*b*. Photometric measure of step density wedge pattern. Light intensities I_A and I_B will produce densities *B* and *A* as indicated on the d log I curve and can be equated to density wedge values.

An examination of Fig. 5.15 will show not only the necessity for plate calibration but also the necessity for calibration at a spectral region in the neighborhood of the lines used for analysis. In actual practice, so long as the same emulsion, developing process, and other factors are controlled it is not essential that more than one calibration curve be established for the spectral range usual in analytical work. Also, where uniform emulsions are available, as in the use of 35-mm motion-picture film, calibration need be applied in intervals, including a number of exposures, or only one or two standard or calibration samples may be applied on each set as a check.

The general methods of applying a calibration pattern to the emulsion are the use of a stepped slit, a stepped wedge, or a stepped sector.

The stepped slit (page 48) and the stepped wedge (involving a transparent plate covered with layers of partially absorbing material such as sputtered metal) are difficult to make and operate, and hence the stepped sector (Fig. 5.5) has increased in popularity as a calibration device. It has also been demonstrated (*C129*) that, for most analytical work, the intermittency and reciprocity failure effects become insignificant when nonsynchronous sector interruptions of 100 or more are used in the exposure.

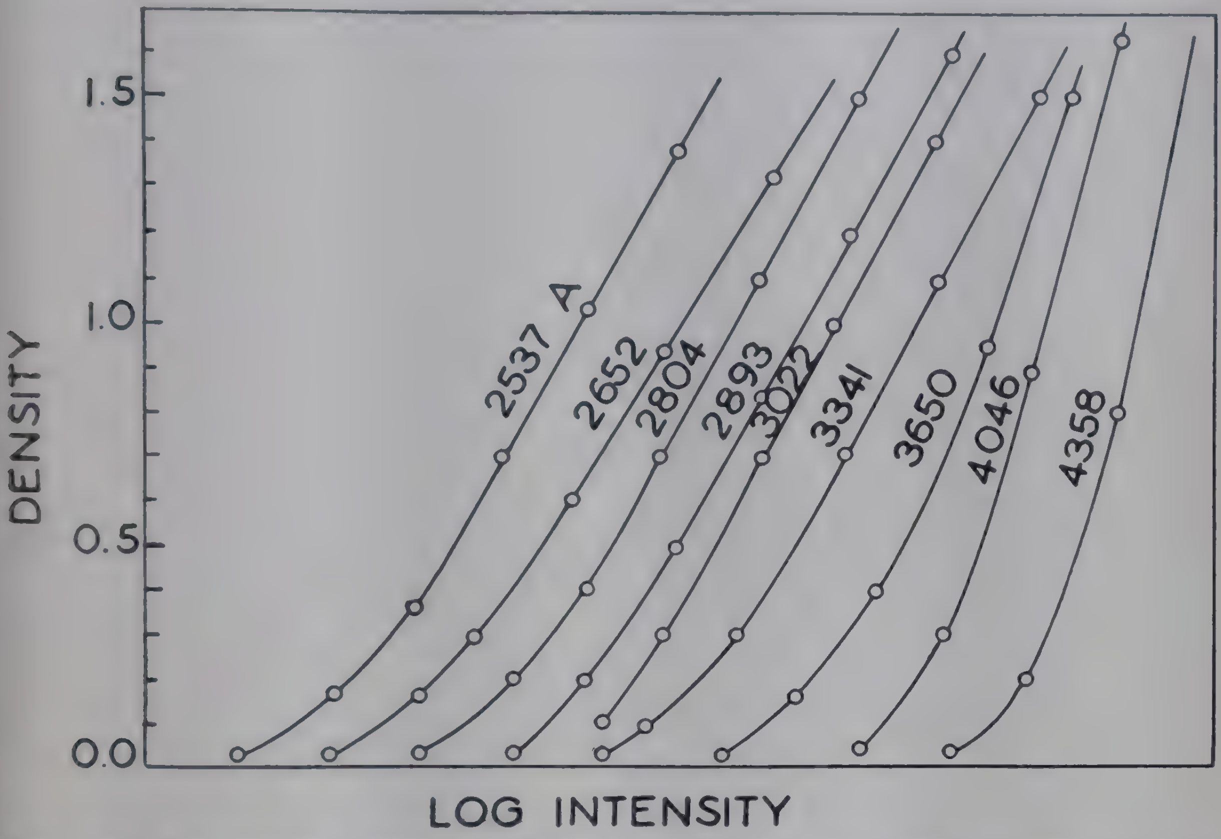


FIG. 5.15. Variation of gamma with wavelength for process plate. (Pierce [*C162a*].)

Since the transmission values of the separate steps are known, the imprinted density patterns on the negative are equivalent to a known change in light intensity. Measurement of the density of the spectrum line as compared with this series of graded densities will enable the observer to assign a definite light intensity value to the line (Fig. 5.14*b*), and hence a comparison can be made of relative intensities of spectral lines with increased accuracy The use of a step logarithmic wedge for plate calibration will yield numerical values for density which will be proportional to the logarithm of the intensity, and the difference in these logarithmic values will be equivalent to a ratio of the line intensities in the source.

The use of a step sector or step wedge at the slit will enable the operator to impress a calibration pattern on the negative for the various

spectral regions included in the plate. The calibration photograph ma
be made separately with a monochromatic light source, or it may b
applied at the time the analysis photograph is made by the use of th
unknown substance in the light source. In the determination of lin
density and light intensity one may determine the d/log I curve fro
this calibration data, or, in the use of the step wedge, slit, or secto
determine the levels at which the unknown and internal standard ar
of equal intensity.

In laboratories where routine analyses are made it has been foun
convenient to mount a calibration source at right angles to the optica
path and to use a right-angle prism which can be easily swung int
position, so as to bring the light path onto the slit. It may be convenien
to mount the stepped sector and right-angle prism together so that the
may be swung into position at the same time.

For most analytical problems a stepped sector with relative opening
of 1, 2, 4, 8 (log values of 0, 1, 2, 3, etc.) and with four or five steps wil
be found to be sufficient. The exposure should be timed so that th
lowest density will be about 0.05 and the higher density values wil
fall on the linear portion of the d/log I curve.

In some laboratories a two- or three-step sector is used on all spectrun
photographs, and the spectrogram to be measured on the densitomete
is chosen so as to be of nearly equal density to that of the known standard or calibration exposure.

The calibration of exposure may be made with continuous or discontinuous sources but should be at a wavelength near that of the lines t
be measured (see Fig. 5.15). (Pierce and Nachtrieb [*C162a*] in usin
process plates have failed to confirm the statement of Strock [*C190a*
that plate gammas as determined from homogeneous and heterogeneou
irradiation will be different.)

The calibration curve can be obtained by plotting the per cent transmission of a line on a log scale against the log of the relative sector ste
openings. Within a limited spectral region a number of lines of different intensity may be used for the preparation of a calibration curve
The calibration of data from more than one line is effected as follows
The log per cent transmission value (d in Fig. 5.1) for an intermediat
sector value (if several steps are available) is located on the curv
obtained from the plotting of the data of the first of a series of lines an
the density intersection with the curve is extended to the log I axis
The additional points are then plotted as multiples of this log I valu
corresponding with the sector ratios. If a sliding log scale is available the selected unit transmission may be set at unity on the log scal
and other density values plotted against the relative sector opening

(such as 0.5), 1, 2, 4 for a sector with four steps in which each transmits twice the next step and in which the second step was chosen as unity.

Two modifications of this procedure are suggested: the use of a two step sector and the use of selected calibration lines in a single spectrogram.

If a two-step sector is used (100 and 50 per cent being the usual combinations) it is possible to plot a curve of densitometer deflection of $D/2D$ and from this curve one can proceed to the $d/\log I$ curve. The use of selected lines in a single photograph requires that a previous step or other calibration method be applied to the series of chosen lines, such as a group of iron lines in the selected spectral region. If the excitation conditions are carefully controlled the relative intensities of the chosen lines can be assigned, plotting these assigned intensities against the deflection will give the calibration curve. In routine analysis where gamma correction curves have been prepared the above modification permits the assignment of the gamma value within a minimum of spectrogram space.

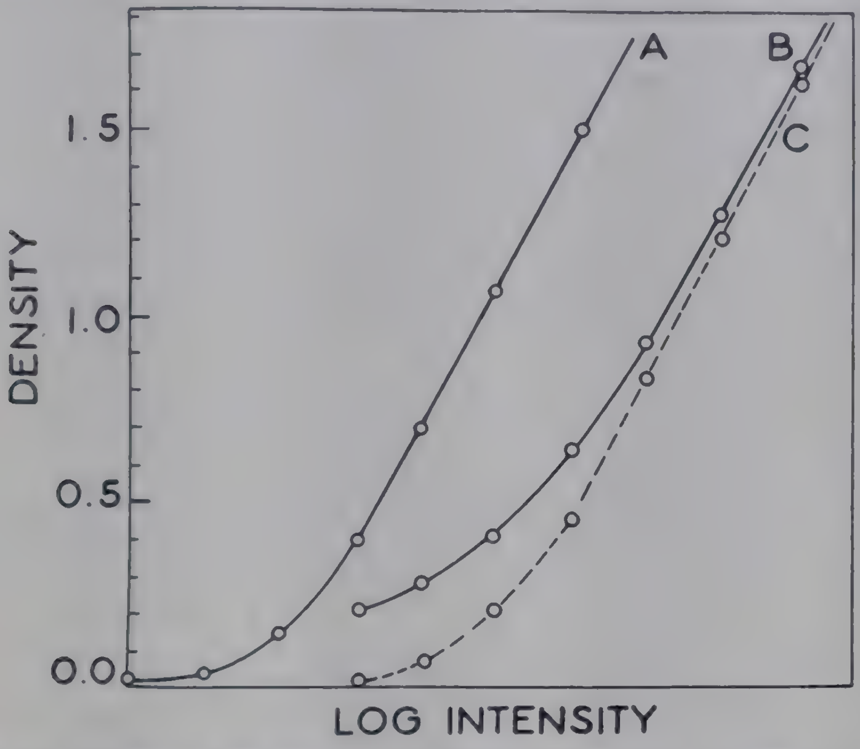


FIG. 5.16. Effect of background on plate calibration. (Pierce [*C162a*].)

BACKGROUND CORRECTION

If there is an appreciable background intensity as compared with the line intensity, it is essential that some correction be made. Such correction is often made by a subtraction of the background density from the total density, but this method does not consider the calibration curve and, though a correction in the proper direction, it is not alway sufficiently accurate. The proper correction is to determine the background intensity and line intensity from the calibration curve and subtract the former from the latter to obtain the true line intensity. Fo an excellent discussion and proof of this correction procedure see Pierc and Nachtrieb (*C162a*). It should be noted that background correctio involves a difference in intensity (*I*) rather than log *I*, and for thi reason it may be convenient to prepare a *d*/*I* curve for calibratio purposes. (See Chapter XII, Exercises 6 and 7.)

In Fig. 5.12 a line density value of 1.37 (*B*) is shown as equivalent to an intensity of 30.8 (*D*) while the background density value of 0.19 (*A* is equivalent to an intensity value of 2.4 (*C*). The difference betweeen these intensity values of 28.4 represents the corrected intensity of the line. The direct subtraction of the background density (0.19 from the line density of 1.37) gives an erroneous line density of 1.18 which corresponds to an intensity of 22.0 or an error of nearly 25 per cent in the determination of line intensity. It should be pointed out, however, that background errors are of little or no importance if the densities of the lines are high and the background density is low (Fig. 5.16).

Line Intensity—Densitometers

Densitometers may be classed as a special form of *photometer* intended for the measurement of optical density. Where the values measured are themselves a direct measure of optical intensity (e.g., photographic

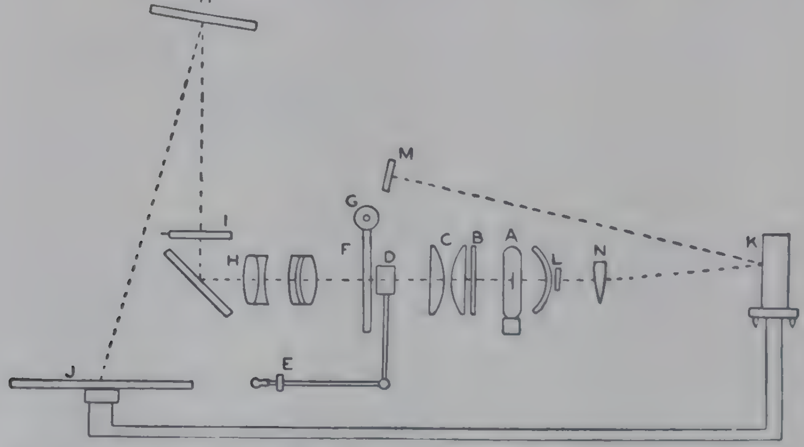


Fig. 5.17*a*. Optical diagram of a single-beam densitometer with slit at projecte image. (Meggers [*C134*].)

blackening) the resulting data may be properly called either *densitomete* or *photometer* values, and a series of values plotted in a curve may b called *densitometric* or *photometric* curves. If the densitometer or photometer is designed to measure light intensity over a limited area such a a slit or pin hole, the instrument is usually termed a *microphotometer* or *microdensitometer*.

The determination of line density as a means of measurement of light intensity can be made by visual comparisons and matching, although nearly always some form of photoelectric or photronic densitometer is used so as to obtain consistent results independent of the operator and more accurate than those obtained in visual matching. In principle these photronic or photoelectric densitometers (Fig. 5.17, 5.18 and 5.19) involve a steady light source of incandescent character, such as a projection bulb, connected through some type of voltage regulator, an optical system to illuminate the plate, and projection of the image produced on a slit in front of the photronic cell, or the focusing of the light on the plate in the form of a line by means of a preliminary slit in front of the light source, and the illumination of the cell with this beam. In some instruments both these methods are employed in that a lamp filament is focused on a slit, the image of which in turn is focused upon the spectrum line on the photographic plate, and the image of this illuminated line is focused on a slit in front of the photocell. This double-slit procedure eliminates a considerable amount of stray lines and permits a more accurate determination of low intensities.

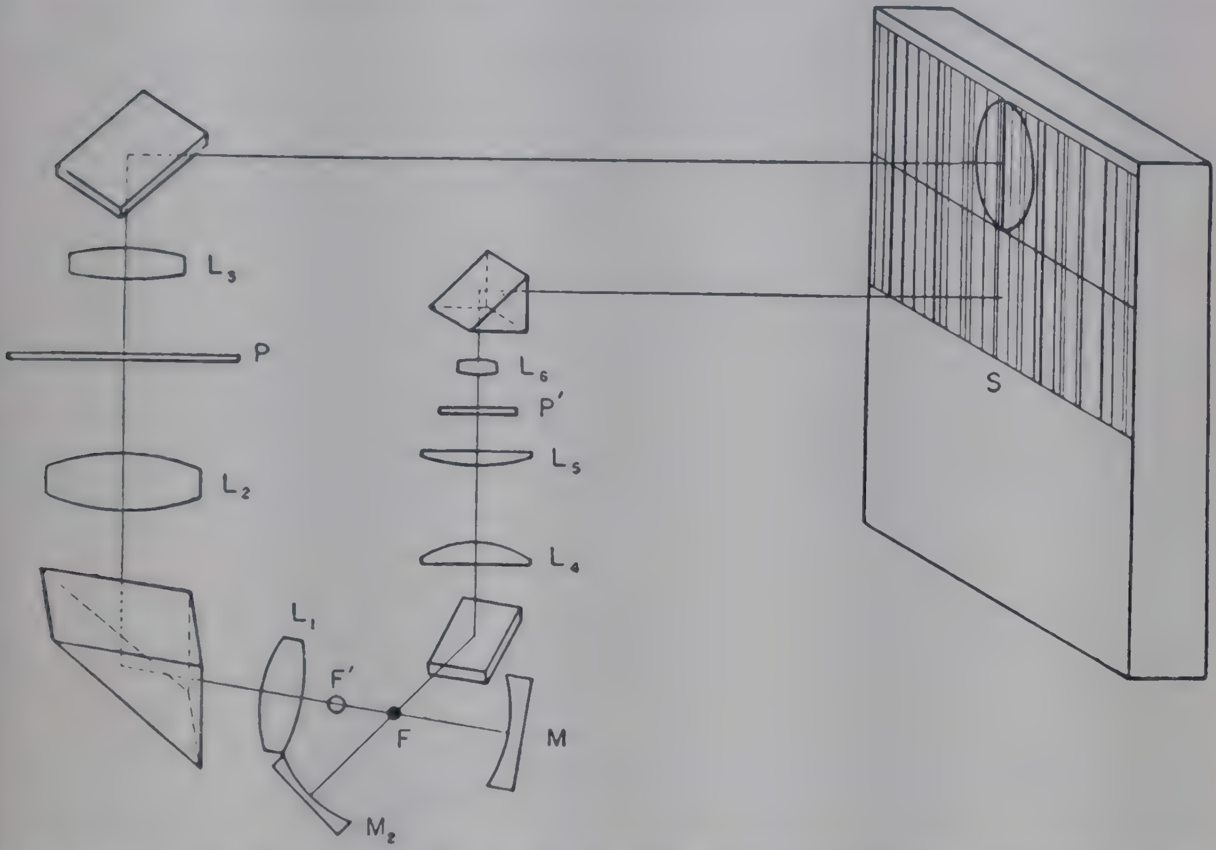


FIG. 5.17*b*. Optical diagram of a double-beam densitometer and comparator with slit at projected image. (Sawyer and Vincent [*C202*].)

The type of photronic cell, photocell, or thermopile has considerabl influence on the data, and it is well to measure the density wedge itsel from time to time to be sure that, over the range in which observation are made, a linear response results from various density values. It may be necessary to calibrate the readings from the photometer in terms o the equivalent density values. Most densitometers operate through a galvanometer electrical circuit so that the density is measured by galvanometer swing. In a few instruments a null method is used with two photronic cells and a bridge balancing device so as to measure the difference between the transparent plate and the spectra line intensity.

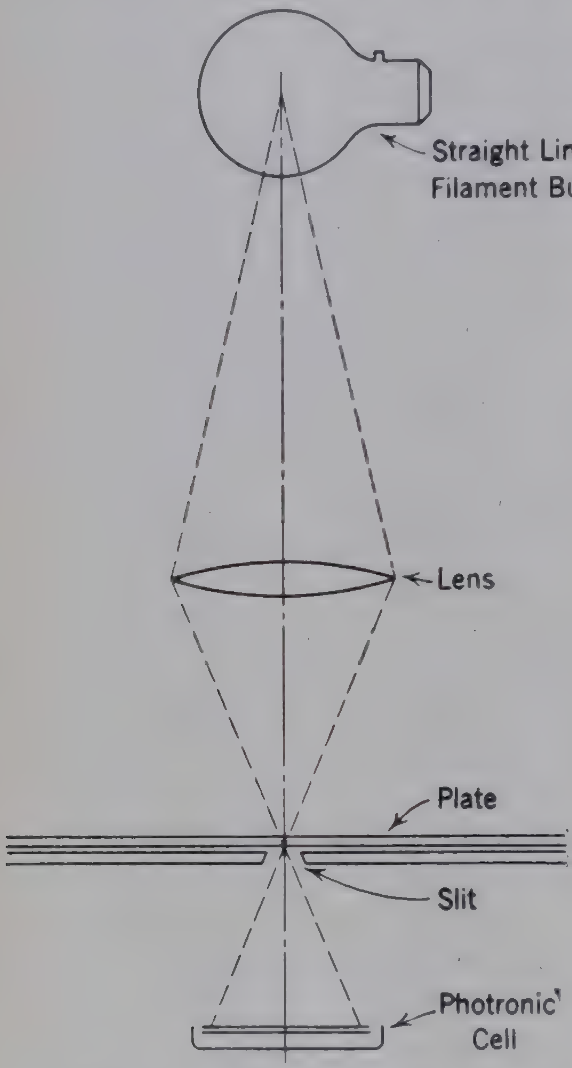


Fig. 5.17c. Optical diagram of a single-beam densitometer with slit adjacent to spectrogram. (Pierce [*C162a*].)

The density of a spectrum line on a photographic plate is a linear function, over a considerable range of the logarithm of the light intensity which produces the latent image.

$$d = \gamma \cdot \log IT \qquad (1)$$

It can be shown that the amount of light transmitted by the spectrum line on the plate can be measured by the galvanometer deflection produced by the current from an interposed photronic cell and that the deflection (D) and density (d) bear a similar relationship to the above intensity and density equation. Deflection is defined as the difference in the galvanometer swing for the line portion of the plate as compared with the galvanometer swing for the clear reading.

$$d = c \cdot \log D \qquad (2)$$

c is a constant characteristic of the photometer.

The measurement of the galvanometer deflection from that of the completely opaque (dark) or from that of a clear portion of the plate is a matter of choice or photometer design. In any instrument, one measures not the galvanometer deflection but rather the relative deflection compared with the deflection range. Most instruments are equipped or can easily be equipped with diaphragms, screens, resistor or slit adjustments by which it is possible to adjust the deflection range to a unit value (usually 100 divisions) and in many cases multiple variations are permitted to allow for more accurate determination of high density values.

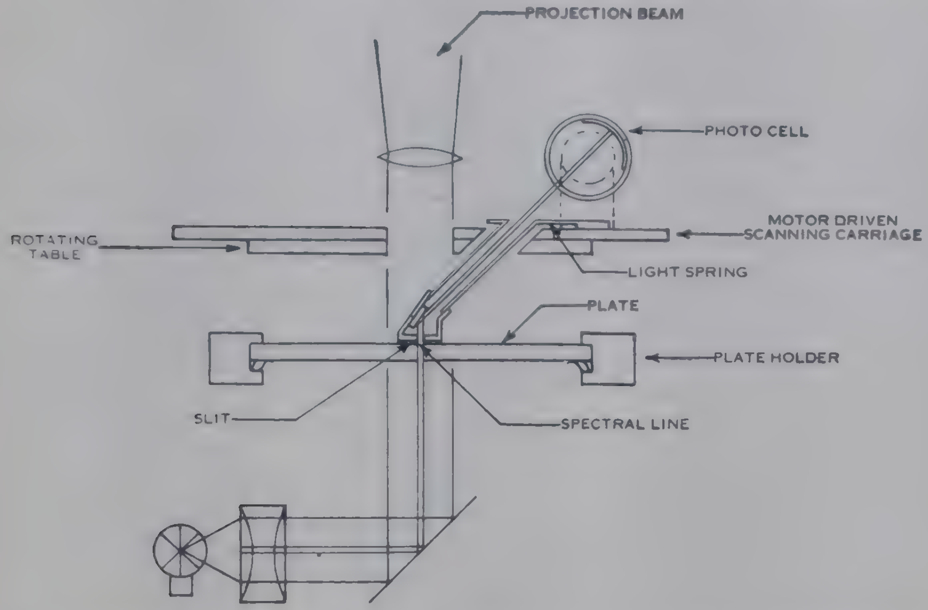


Fig. 5.17*d*. Optical diagram of densitometer portion of a comparator-densitometer with slit adjacent to spectrogram (see Fig. 5.19*c*). (Applied Research Laboratories—Dietert.)

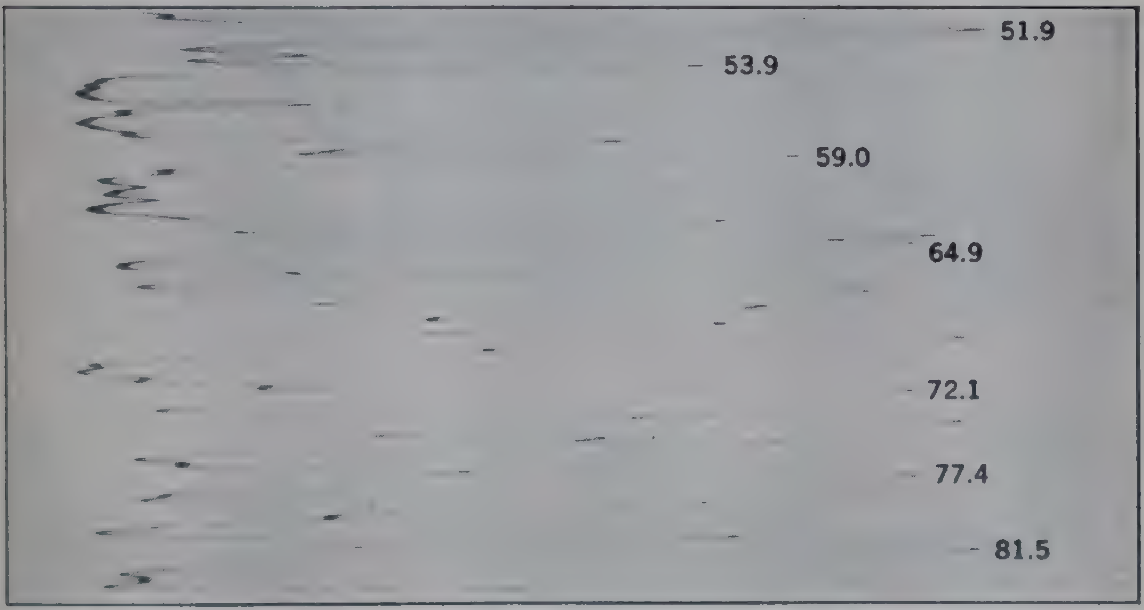


Fig. 5.18. Microphotometer record of steel spectrum (2850 to 2885 A), taken on a Moll (Kipp and Zonen) instrument.

The principle of quantitative spectrographic analysis involves the intercomparison of lines of the internal standard and unknown. If d_1

and d_2 represent the densities of the standard and unknown lines then th difference in density Δd may be equated to

$$\Delta d = d_1 - d_2 = \gamma \log I_1T - \gamma \log I_2T = \gamma \log I_1/I_2 \qquad (3$$

also

$$\Delta d = \log D_2 - \log D_1 = \log D_2/D_1 \qquad (4$$

hence

$$\gamma \log I_1/I_2 = \log D_2/D_1 \qquad (5$$

The plotting of the value log D_2/D_1 against the percentage compositio and log percentage composition will give the required working curv for chemical analysis. In general the recording of the log deflection rati against the log percentage composition will give a straight line whos slope will be determined by the gamma value of the photographic plat

TABLE 5.4

WORKING CURVE DATA

Quantitative Spectrographic Analysis for Tin (Sn 3175.1)
Internal Standard Bismuth (Bi 2989.1)

(*Silica-Alumina Base*)

Concentrations				Logarithmic Sector Method			Densitometer Method (Clear deflection = 17.7)			
				Lengths of Lines			Deflection		Ratio I_{Sn}/I_{Bi}	Log Ratio I_{Sn} I_{Bi}
No.	Bi %	Sn %	Log Sn %	Bi	Sn	Sn—Bi	D_{Bi}	D_{Sn}		
1	...	...	...	...	1.5	...	...	...	...	...
2	1.5	...	...	5.5	3.3	...	42	...	...	...
3	1.5	0.15	−1.176	5.7	4.7	−1.0	42	75	0.74	−1.87
4	1.5	0.25	−1.398	5.2	5.3	+0.1	40	41	0.99	−1.99
5	1.5	0.35	−1.544	5.4	7.0	+1.6	40	17	1.36	0.13
6	1.5	0.45	−1.653	5.0	8.1	+3.1	43	10.5	1.68	0.22
7	1.5	0.55	−1.740	5.0	8.9	+3.9	42	7.5	1.89	0.27
8	1.5	0.65	1.813	4.5	9.5	+5.0	41	6.0	2.03	0.31

The gamma value can be independently determined by the use of density pattern (step or logarithmic wedge imprint on a portion of th plate) although one should realize that the gamma value is not the sam for all wavelength values, usually dropping as one proceeds towards th lower-wavelength portion of the spectrum. For many forms of analysi the gamma obtained by a careful control of the illumination and de velopment conditions is sufficiently constant so that repeated plat calibration patterns are not always essential in routine work.

Plates with a high gamma such as Eastman Spectrum Analysis No. 1 will give satisfactory measurements over a limited concentration range, whereas plates with a lower gamma such as Eastman No. 33 will cover a wider concentration range, but with a corresponding decrease in the accuracy in the determination of the percentage concentration.

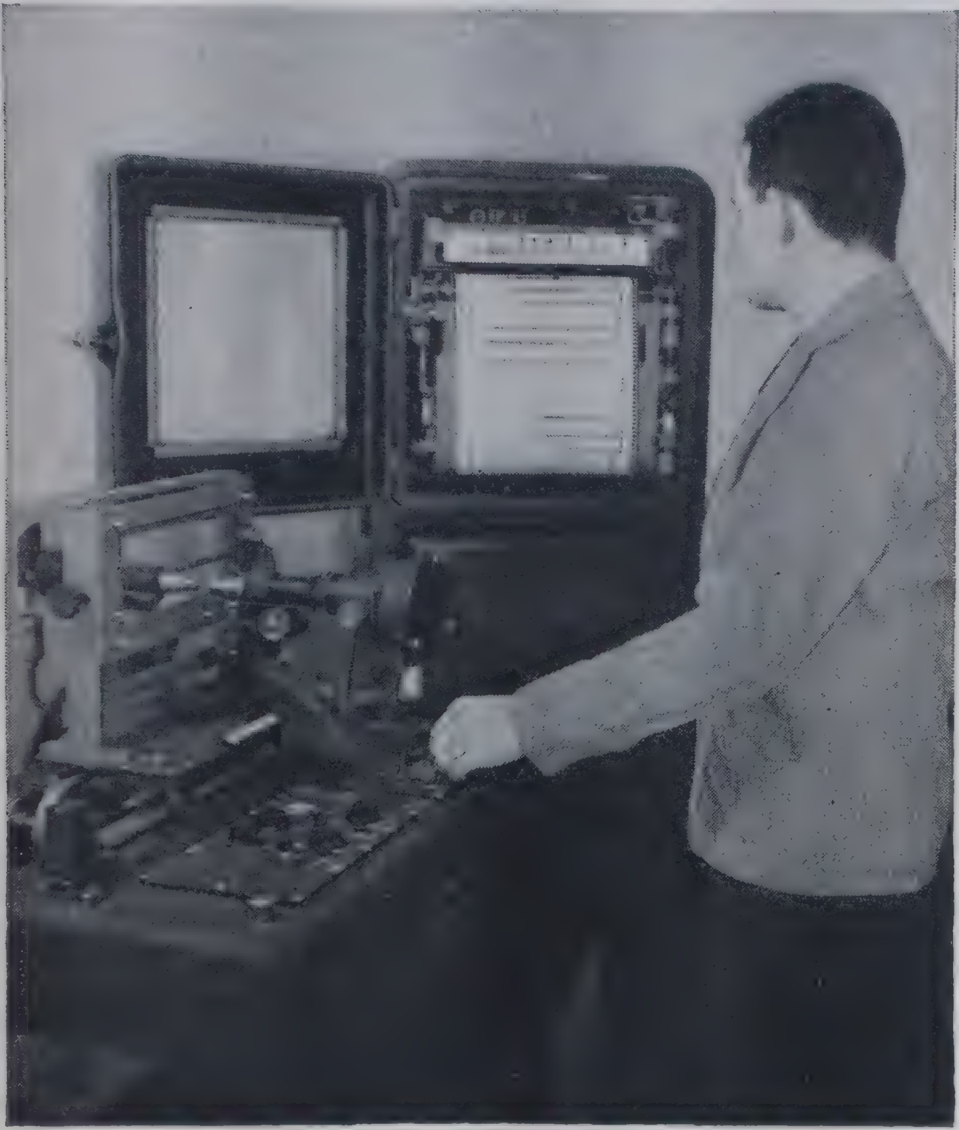


FIG. 5.19*a*. Leeds and Northrup recording densitometer.

The effect of a continuous background, if small, can be corrected by the measurement of the deflection of the galvanometer for a clear portion of the spectrum adjacent to the lines to be measured, and the determination of the total line deflection by the difference between this value and that of the observed deflection for the spectrum line. Where the background is more intense it is necessary to apply an equation such as

$$\Delta d = d_1 - d_2 = \gamma \log (I_1 + i_1)/(I_2 + i_2)$$

in which i_1 and i_2 represent the background intensity adjacent to the tw lines under observation (*A104* and *C146*).

Densitometers

The principal commercially available photometers for simple pla reading include those produced by Zeiss (*C115*), Bausch and Lomb (*C8* Leeds and Northup (*C128*), A.R.L-Dietert (*C72*), General Electr (*C129*), Sawyer and Vincent (*C202*), Baird (*C6*), and Hilger and Gaertn (Figs. 5.17 to 5.19). In some of these instruments a continuous pla motion has been incorporated to improve the analytical measurement and visual observation is made of the maximum swing of the galvanometer. This plate motion during observation eliminates possible erro arising from positioning of the plate in the photometer. For mos analytical work the recording type of photometer is not at all essenti since only one or two lines are to be measured and the density observe is immediately converted into some other quantitative value.

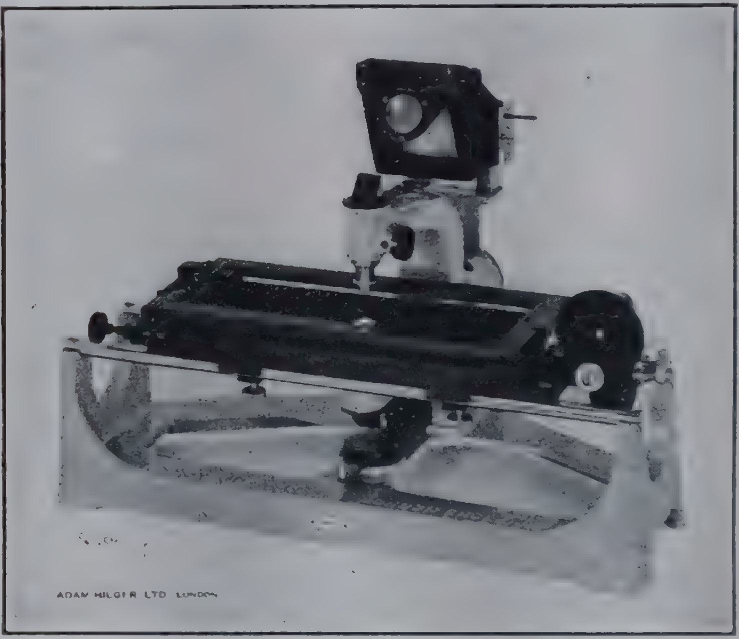


Fig. 5.19*b*. Hilger densitometer (Jarrell-Ash).

The Leeds and Northrup, the Zeiss, and the Moll instruments recor the galvanometer swings directly on a pen tracing, photographic plat or photographic paper. The instrument designed by Harrison for use the Massachusetts Institute of Technology for the measurement wavelength values includes a photoelectric device for measuring li density and recording it on a photographic film. Recording microphoton eters are so operated as to scan the photographic plate at a constant speed, and hence, with a galvanometer of known period, it is possible to obtain results which can be easily duplicated.

Some densitometers have adjustable diaphragms or resistance circuits so that the scale can be adjusted to read 100 divisions for a clear portion of the negative adjacent to the line to be measured. The deflection value of the line thus becomes the percentage of light transmitted by the line. Such a measurement provides a correction for background as well as indication of line density. Reference to the calibration curve (*d*/log *I*) of the negative will give the logarithm of intensity equivalent to this deflection. The difference between the logarithm of intensity for the unknown and the standard will bear a linear relation to the log per cent of unknown element present.

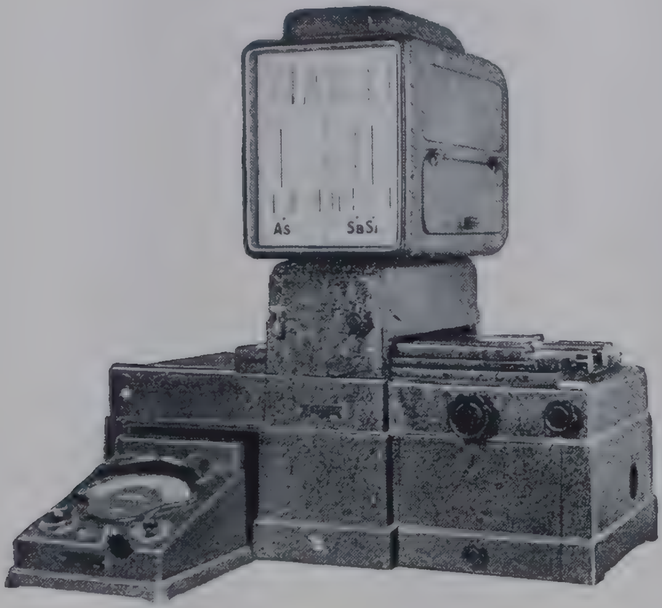


Fig. 5.19*c*. Applied Research Laboratories comparator-densitometer (H. W. Dietert Co.). See Fig. 5.17*d*.

Pierce and Nachtrieb (*C162a*) have suggested a densitometer type (Fig. 5.17*c*) which involves the focusing of the light source on the slit which is put in front of the photronic cell and placing the spectrum plate immediately in front of this slit so that the emulsion is about 0.2 mm from the slit. The slit was about 1.5 by 0.015 mm. This densitometer, like many others, is equipped with a sensitivity adjustment to permit a scale reading of 100 for I_0 or clear transmission so that the galvanometer readings plotted on a log scale become density values (provided that background correction is not necessary).

Calculating Boards

In the industrial application of the spectrographic method of analys it has often been found convenient to use a calculating board up which one can set values corresponding to plate characteristics and t

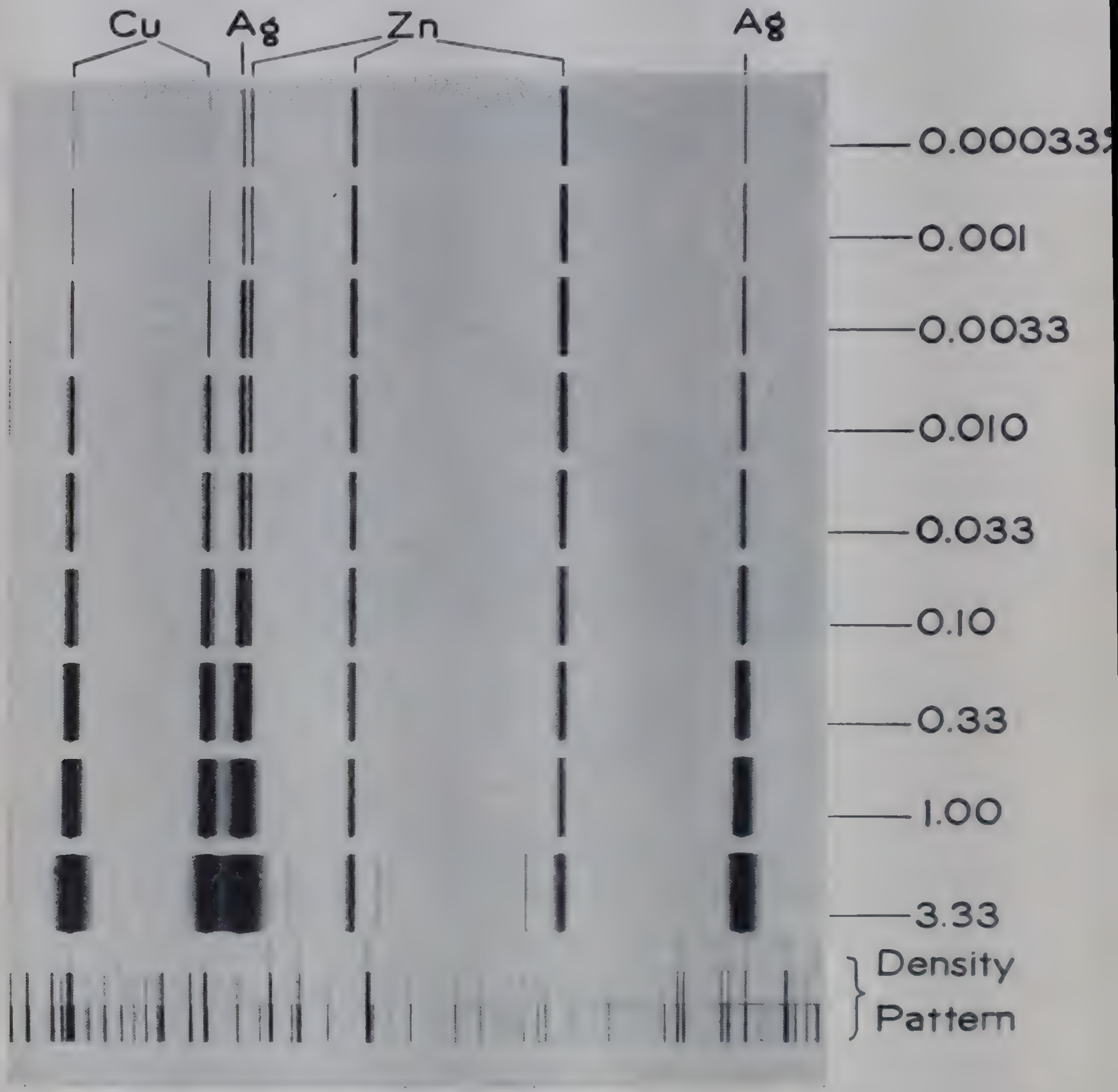


Fig. 5.20. Spectrogram for preparation of densitometer working curve. N.

line sensitivity and obtain a direct measurement of the percentage composition from the galvanometer observation.

These calculator boards have been devised (*C156*) with an "analytica scale" ruler prepared from the working curve (Fig. 5.22). When the zer value of the analytical ruler is set at the intercept of the standard densit value with the plate calibration curve, the percentage of unknown ca be read directly from the ordinate extended from the intercept of th unknown line density and the calibration curve (Fig. 5.23).

The zero scale value, as can be seen in Fig. 5.22, is the per cent concentration of the unknown yielding a line equivalent to the known reference line in intensity. For each pair of line combinations a different

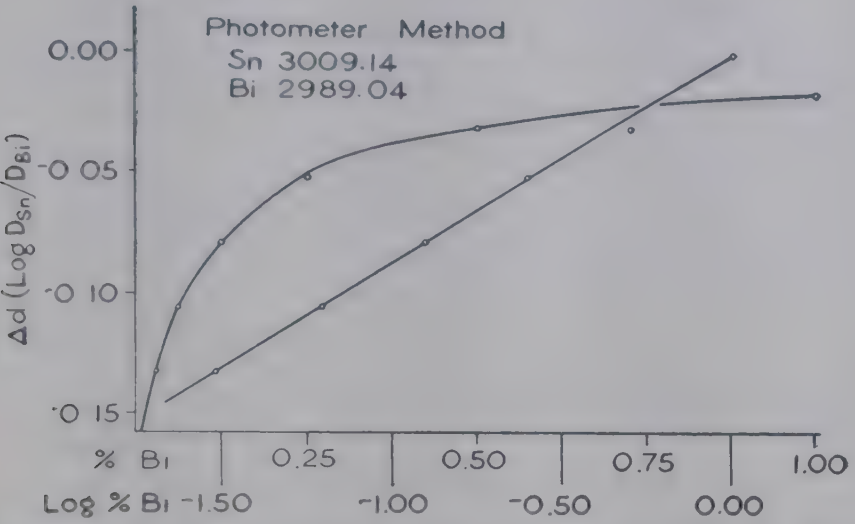


FIG. 5.21. Working curve. Densitometer (photometer) method.

Note: In the densitometer method, line density differences (Δd) are usually recorded as the abscissa with increasing values indicating increasing concentration of the unknown. In the above example some workers would replace the Δd term with log I_{Bi}/I_{Sn}, or merely log Bi/Sn. The former is not quite correct since it should be δ log I_{Bi}/I_{Sn}, and the latter expression (log Bi/Sn) is only symbolic. Other workers use the expression log D_{Sn}/D_{Bi}, which is correct, but the corresponding symbolic abbreviation log Sn/Bi causes some confusion.

The line data such as the ratio Sn 3009.14/Bi 2989.04 are sometimes expressed with the internal standard as the numerator, or in reverse, Bi 2989.04/Sn 3009.13, with the standard as denominator.

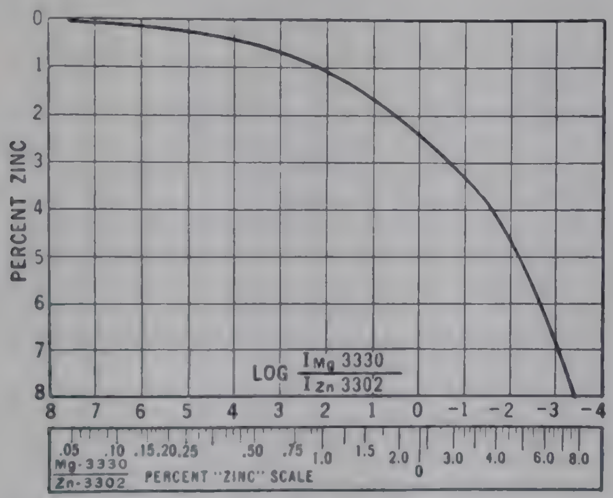


FIG. 5.22. Preparation of analytical scale. (Owens [*C156*].)

analytical scale may be used, or if extraneous effects are not large a log scale may be substituted for the analytical scale. With this log scale, there will be separate factors for each element which must be set at the intercept of the intensity internal standard line and the calibration curve. The d/log I curve of the negative can be obtained by plotting t calibration-pattern densities against (1) known log density values obtained from the logarithmic step sector or exposure time used calibrate the plate, or against the known concentrations of the "u known" in standard samples used for calibration. The log I scale of t calibration sheet should, of course, be on the same scale as the log I cur used in preparation of the analytical scale.

In commercial analyses in which the samples are similar it may onl be necessary to take two or three standard or calibration sample phot graphs to indicate the calibration curve to be used. The calibration curv

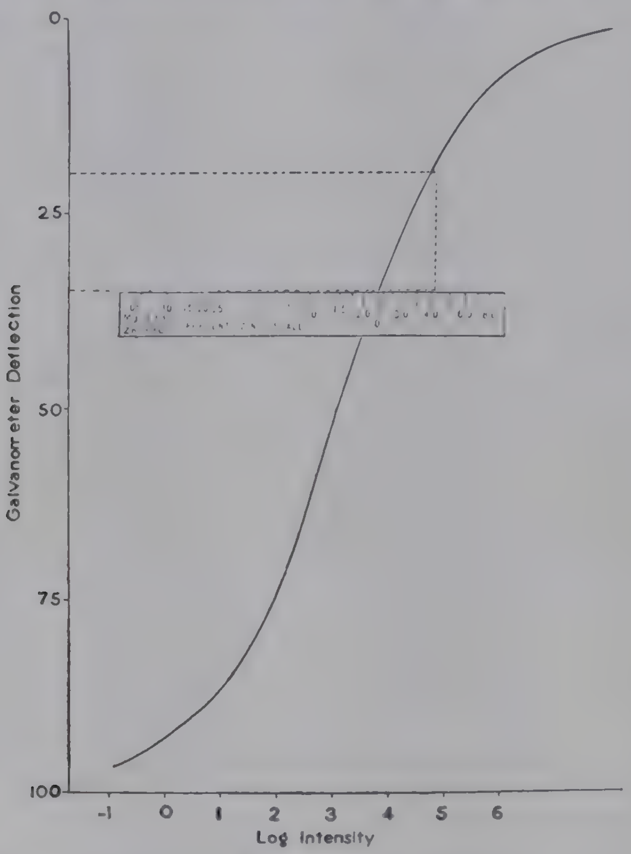


FIG. 5.23. Application of analytical scale to calibration curve. (Owens [$C156$].

becomes the d/log I curve of the negative when the deflection reading of the photometer are equivalent to the line density. When the deflec tions are not equivalent, the calibration curve includes photometer a well as negative correction.

The deflection value of standard lines can be extended on the d/log (log per cent transmission/log I) curve to the log I axis and a slidin log scale set at unity at the intersection. The deflection values o unknown lines on extension to the sliding log scale are thus rea off directly in relative line intensities. These may be converted in to elemental per cent composition from the working curve, or by factor since the relation is linear over a considerable range. One ma substitute a graduated per cent composition scale for the analysis element in place of the sliding log scale.

In routine industrial analysis where the same methods of excitation and types of samples are used on the same instruments, it is possible to develop a standard technique or routine which permits the rapid analysis of many samples provided that constant working conditions are maintained. This includes, of course, the same types of developer, plate emulsion, and many other factors. Careful calibration curves should be obtained for the photographic plate or film material, and on each unknown plate a certain number of standard knowns should be included. If three known samples are included in which the concentration of the unknown varies over the range desired, the deflection values obtained can be compared against a standard calibration curve, the data for which have been carefully determined with similar calibrated plates. If the data on the three knowns correspond with the standard calibration curve, then it may be assumed that the plate calibration of the standard curve and the negative observed are similar. If the deflections of the calibration lines do not conform to the calibration I curve, then their variations from the standard curve provide a factor which must be applied to the deflections of the unknown sample lines in order that they may be reduced to the standard curve so as to determine elemental concentration.

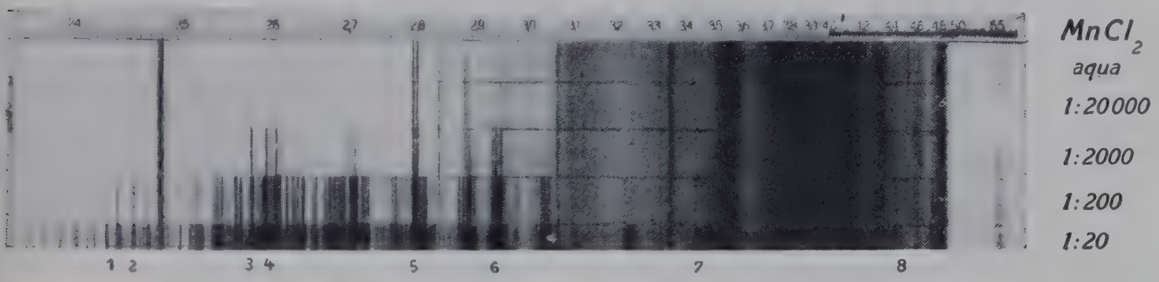


FIG. 5.24. Portion of a spectrogram, **N**, from the quantitative charts in Lundegårdh's "Die quantitative Spektralanalyse der Elemente" (*A68*). Illustration shows one fourth of a chart reduced to two thirds scale.

APPLICATION OF QUANTITATIVE SPECTROGRAPHIC ANALYSIS

Gouy, Watteville, Gooch, and Hart (*C92*) had used the spectroscope as a means of qualitative identification of potassium, but it remained for Klemperer (*C116*) to indicate a quantitative relation between the intensity and analytical values. Lundegårdh (*A68*) has developed quite an extensive system of quantitative spectrum analysis through the use of a flame, arc, or spark source. In the application of his solution method Lundegårdh has published data using an internal standard (quite often aluminum chloride), and measuring the line density with a thermoelect densitometer. Some ten years later Lundegårdh published a second pa to his book (1934) in which he has used an immersion arc and spa holder for study of solutions, and included numerous tables of accep able lines for analysis purposes, especially for the rare earths. The dat by Lundegårdh provide the best available material on quantitati flame spectra analysis.

The linear relation involved with the logarithm of the percentag composition indicates that the accuracy of the method will be a functio of the amount present rather than an absolute value. In general, on can obtain results accurate within 5 per cent of the amount present ove the effective range of the working curve. The choice of concentratio of the internal standard should be such as to yield a line density equivalent to the density of the unknown line at about the intermediate concentration value of the range over which the working curve is to b applied. The literature available on the determination of high percentag concentration of elements by this method is meager, but there appear to be no reason why a weaker spectral line of proper characteristics coul not be used for the unknown element in a rather high concentration, t compare with the internal standard line, although one could not hope to increase the accuracy above 5 per cent of the total amount. In observations involving a nearly pure material it would be more to the point to determine the impurities directly and the element in high concentration by a method of difference or remainder.

Menzel has suggested that for stellar quantitative analysis as well as laboratory technique it should be possible to set up a series of curves or tables which, for certain pairs of lines of the same element but different excitation potential, should determine the excitation conditions of the source. Furthermore, it should be possible to formulate a working curve for each of these determined or assigned excitation regions so as to express the elemental concentration of the component elements in terms of a major constituent element which has been chosen as a control or internal standard. The influence of certain elements on the line intensity of other elements would, of course, be a disturbing factor which would have to be considered (*C105*).

The sensitivity of the spectrographic method of analysis is well illustrated by the work of Cholak (*C61*) in which elemental concentrations in biological materials were determined in concentration ranges of 0.0001 to 0.00001 per cent. The lines selected by Cholak for estimation of elemental concentration correspond closely with the important lines (bold-face designation in Table IV, pages 408 to 409) selected by Pierce (*C162*).

Influence of Extraneous Elements

A small amount of mercury produces a marked effect on the spectral intensity of neon in a discharge tube, since the spectrum of neon is practically eliminated owing to the low ionization potential of mercury and the high ionization potential of the neon atom. This effect has been noted by other workers in arc and spark spectra, and an ordered arrangement of elements has been attempted in which those above a given element would tend to decrease the spectral intensity while those below would increase the spectral intensity of the element under test. Gerlach and Schweitzer (*A28, 30*) have shown that potassium chloride could be added to a 1:1 zinc chloride-cadmium chloride solution until the solution contained 32 per cent of potassium chloride with no perceptible change in the intensity ratio of the zinc and cadmium lines. D. M. Smith (*C186*) also has pointed out that it may generally be assumed that the presence of other impurities than the one under investigation usually has no effect upon the intensity of the lines due to the unknown element. This assumption seems justified for small quantities of the extraneous elements (less than 1 per cent).

Zinc-cadmium and zinc-iron alloys which were carefully analyzed and shown to contain a variety of other elements gave satisfactory correlation in relative line intensities as compared with the standard alloys prepared especially for control and known to be free from these impurity elements. From these and other data, Smith concludes that it may be generally assumed "that the presence of other constituents than the one under consideration has no effect on the intensity of the lines due to that constituent."

On the other hand, T. Negresco (*C152*) states that in a given alloy the introduction of a third metal totally changes the sensitivity of the spectrum lines of the other two elements, and cites a copper alloy containing 10 per cent of manganese and 0.1 per cent of aluminum. In the observed spectrum the aluminum lines were practically suppressed. In this alloy, however, the manganese occurs in a comparatively large quantity, and thus apparently has a more pronounced effect than if it were present only as an additional impurity, i.e., 1 per cent or less. A similar example is the effect on cadmium lines in a zinc alloy when varying amounts of lead and iron are added.

Van Someren (*C199*) has reported the similar effects of some 10 per cent silicon in an aluminum alloy, and 10 per cent zinc in a similar alloy, both causing a lower intensity in the impurity lines and hence a lower spectrographic analysis figure as compared with the chemical analysis. As a reversal of this effect it may be pointed out that a small amount of material, such as 0.5 per cent tin or arsenic in copper, has been report to cause a marked increase in the density of the copper lines.

Duffendack, Wolfe, and Smith (*C76*), in comparing the intensity barium lines in nickel and nickel-copper alloys, noted that the copp had an appreciable effect on the relative intensities of the barium line These examples thus confirm the general principle that due considera tion must be given to the effects of each substance present on the lin intensities of all the other substances present. For accurate analyses thi would involve the preparation of standard or working curves with a nearly as possible the same content as the unknown, and, where mor than one unknown is present in variable amounts, the working curv experimentation should include a study of the effect of the variation o each constituent on all the other constituent line intensities.

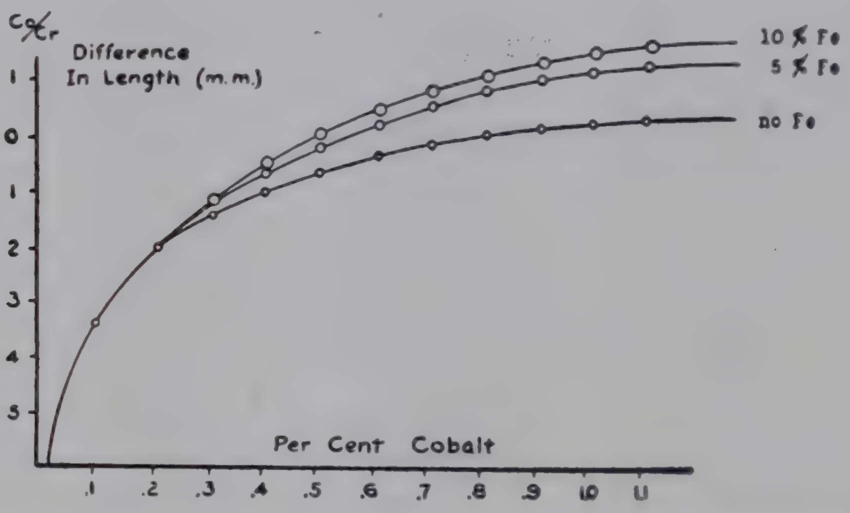


FIG. 5.25. Influence of iron on the working curve for cobalt. Line pair Co 3405.1/Cr 3403.3. (Twyman and Hitchen [*C195*].)

Such a series of experiments was carried out by Twyman and Hitchen (*C195*) in which they studied the influence of iron and copper on the intensities of nickel and cobalt, using chromium as the internal standard (Fig. 5.25). From these data they concluded that, although many complex factors may take part in the influence of one element on the line intensities of another, the effect is not so great but that a direct examination of the unknown substance will give the concentration of the constituents to a first approximation. A series of known standards can then be prepared and the influence of the variation of the constituents present on the line intensities of each other can easily be determined. This correction can then be applied to the original unknown analysis, or, if a series of samples are to be run, a working curve may be set up for the particular type of material under observation.

Duffendack, Wiley, and Owens (*C77*), who have further investigated this effect of one element on intensities of another, group these variations into two types: those dependent on solution characteristics, and those dependent on elemental interactions in the vapor state in the arc or spark. Sodium, potassium, and magnesium were found to decrease the line intensities of certain elements, while calcium enhanced the intensities of the potassium and magnesium with respect to cadmium.

Negative ions are known to have some effect on line intensities, and it is reported that the chloride ion increases the intensities of lines without changing the relative intensities, while sulfate and phosphate ions are reported to cause a decrease in intensities without an appreciable change in relative intensities.

Personal observations by the author have indicated that in certain substances, such as the chlorides of the alkali-earth metals, a considerable amount of the element is excited as the calcium, strontium, or barium subhalide to give the corresponding diatomic band spectra. In fact, a method for the determination of fluorides has been reported in which the salt is mixed with calcium carbonate and arcked. The intensity of the calcium fluoride band spectrum is used to determine the amount of fluoride present. Certainly a portion of the alkali-earth metals, at least in low-temperature arcs, is excited in the form of the oxide rather than the elemental state, and this would apply to the sulfate and phosphate salts which would yield oxides at the arc temperatures.

A rather important observation was made by Duffendack, Owens (*C108*), et al., namely, that the influence of the extraneous element on the line intensity of the impurity, as compared with an internal standard, reached a maximum value, and, by what might be termed a method of excess, i.e., addition of an excess of this extraneous element, it was possible to eliminate the necessary consideration of the effect of the extraneous element on the unknown. An excess method sometimes reduces the sensitivity of the unknown lines by slight changes in percentage composition. This was especially true of the addition of potassium in excess to an unknown containing calcium. Other workers in the field of spectroscopy have suggested the possibility of establishing an ordered arrangement of elements, much as in an electromotive series, in which the order follows the ionization potentials, with the indication that any element might have its lines depressed or enhanced by elements above or below it in the series. There appear to be numerous exceptions to this order, however, and further work seems to be necessary in this field.

Breckpot, Creffier, and Perlinghi (*C13*) have shown that the addition of quantities smaller than 0.3 per cent of an extraneous element to a binary system had little or no effect on the relative intensities of the binary components, and in some instances as much as 3 per cent wa added before any measurable effect could be noted.

To supply further information on this problem of influence of line intensities, Brode and Silverthorn (*C51*) have prepared a series of sample of cadmium and zinc, using in the analyses the homologous pairs o 3252.5 (Cd) and 3345.0 (Zn). The mixtures were made up in an alumina silica base of constant composition, and to avoid chemical reaction th salts were either carbonates or sulfates but not mixtures of carbonate and sulfates. In the samples studied a mixture of 4 parts of cadmium a carbonate with 1 part of zinc as carbonate was mixed with 10 per cent o this amount of each of the following metals as carbonates: sodium, potassium, lead, magnesium, copper, and bismuth. It was found that onl the last two in this concentration had an appreciable effect on the relative intensity of the Cd-Zn lines, and their effects were in opposite directions. The presence of copper reduced the intensity of the Zn line as compared with the Cd line (Fig. 5.26). Bismuth, on the other hand, reduces the intensity of the Cd line as compared with the Zn line.

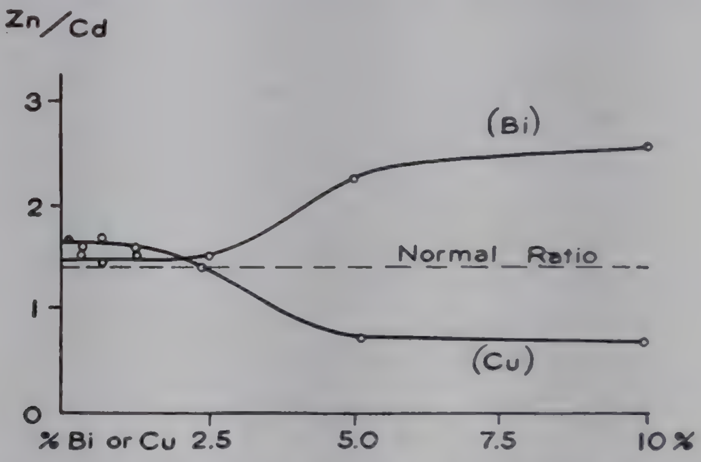


FIG. 5.26. Influence of Bi and Cu on the Zn/Cd line ratio (carbonates) (Brode and Silverthorn [*C51*]).

Brode and Appleton (*C32*) have shown that the extraneous element may influence the intensity ratio of certain pairs while others remain unaffected. This effect is shown when nickel is present as an extraneous element and shows a slightly positive effect on the Mg 2853/Pb 2833 A ratio, whereas in the Mg 2802/Pb 2833 A ratio a marked negative effect is noted. From these data it would appear that the Mg 2852/Pb 2833 A ratio would be more acceptable for analytical studies in view of its slight change with a change in concentration of the extraneous element. The influence of extraneous elements has been demonstrated by Churchill (*C62*) in the effect of magnesium on the copper and aluminum line intensities as well as the ratio of their intensities (see Fig. 5.27).

A study of the influence of extraneous anions on line intensity has been made by Brode and Hodge (*C42*), and it has been shown that, in a series of compounds of different anions but common cations, the line intensity of the cation is quite satisfactory for those compounds or their decomposition products having the lowest boiling point. The same type of extraneous effects has been noted in studies which have been made (*C33*) on the effect of large amounts of iron on the suppression of the sensitivity of the boron lines. From these studies of extraneous-element influence on the relative intensity of line pairs it would appear that the effect is limited to certain concentration ranges and that on either side of the sensitive region the effect can be considered constant in character. It has also been shown that the effect may be positive as well as negative with regard to the influence on line intensity.

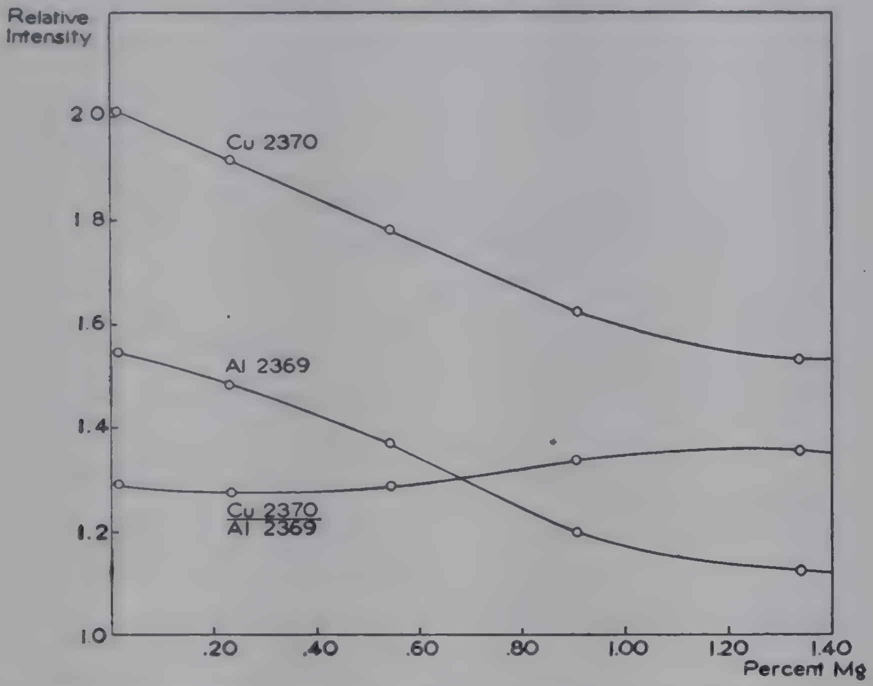


FIG. 5.27. Influence of magnesium on the copper aluminum intensity ratio. (Churchill [*C62*].)

CHOICE OF INTERNAL STANDARDS

For complete quantitative analyses it is recommended that working curves be prepared in which the extraneous elements are in equivalent quantity to that of the unknown series, and, where some doubt exists as to their effect, a set of working curves should be prepared with different concentrations of the extraneous elements. It is therefore impossible to publish satisfactory working curves for general application although each individual worker can rely on them for the particular problem for which he has prepared the proper standard series. The spectrographic analyst can be assisted, however, by the publication of lists of pairs of lines which are known to furnish satisfactory data for analytical workin curves. Lundegårdh (*A68*) and Gerlach (*A29*) have published such lists

Other methods which have been suggested for the intensity determination of lines in an emission spectrum include the direct measurement o line intensity by means of a monochromator and photoelectric cel system, and the use of a moving plate on a known amount of sample in a controlled arc so as to measure the duration of the line in the arc. Neithe of these methods is integrating in character, as is the photographic plate and therefore they depend on sufficient intensity of the line to affect the cell or the momentary exposure which is given to the plate.

One might classify the methods of quantitative analysis as follows: (1) the length of lines in the spark discharge, (2) the number of lines recorded on a plate after a controlled exposure, (3) the intensity of lines on a plate, (4) the time for disappearance of lines in a standard arc, and (5) the direct photoelectric determination of line intensity by means of a monochromator. Of the various methods the second (number of lines on a plate [Hartley]) is the earliest. The most successful results have involved the third method (intensity of lines on the plate). The average quantitative spectrographic analysis can be effected with an accuracy of about 5 per cent of the amount present, and where care is taken in the control and observation conditions the accuracy can be improved to 2 to 3 per cent of the amount of the element present.

LITERATURE

General

G. SCHEIBE, "Chemische Spectralanalyse" (*A81*).

W. GERLACH and others, "Chemical Analysis by Emission Spectra," 3 volumes, (*A28*) (*A29*).

W. SEITH and K. RUTHHARDT, "Chemische Spektralanalyse" (*A84*).

H. W. THOMPSON, "A Course in Chemical Spectroscopy" (*A101*).

H. LUNDEGÅRDH, "Die quantitative Spektralanalyse der Elemente" (*A68*).

D. M. SMITH, "Metallurgical Analysis by the Spectrograph" (*A85*).

F. TWYMAN, "The Spectrochemical Analysis of Metals and Alloys" (*A104*).

CHAPTER VI

RESONANCE AND CHEMICAL STRUCTURE (*B36*, *B63*, *B64*)

Compared with the simpler di-, tri-, and symmetrical polyatomic compounds described in Chapter II (p. 23), the more complicated unsymmetrical absorbing molecules produce a very complex vibration and spectrum. It is difficult to set up exact limitations, for rules and effects which may apply in one case may not in another. With the exception of certain colored ions it is usual to have a number of atoms together, rather than a single atom, as the nucleus or resonating system. This nucleus of resonating atoms is known as the *chromophore* of the molecule, and a molecule containing such a group of atoms is known as a *chromogen*. The shift of an absorption band as a result of some external action on the chromophore is termed a *hypsochromic* effect if it involves a shift to higher frequency values and a *bathochromic* effect if it involves a shift to lower frequency values.

It is sometimes difficult to define precisely the size or sphere of influence of a chromophore, especially when the molecule contains a large number of similar atoms, as do the organic compounds. All atomic linkages such as C—H or O—H will have resonating properties and will produce absorption spectra, but these simpler linkages produce rotational effects which are to be found only in infrared, Raman, and extreme ultraviolet spectra (see Chapter X on infrared spectra). Within the visible, the near infrared, and the photographically available region of the ultraviolet, the simpler absorbing or resonating groups all seem to involve two or more atoms coupled together by the sharing of four rather than two electrons. The commonly known chromophores include C═C, C═N, C═O, N═O, N═N, C═S, etc. In such groups (Fig. 6.1) it is to be noted that there is apparently an outer satisfied shell surrounding the entire unit of the two coupled atoms, but that within the completed shell there is a condition which the organic chemist terms unsaturation. The molecule is capable of absorbing additive substances such as H_2, Br_2, and H_2SO_4. This unsaturated or resonating nucleus, as Pauling (*B64*) has shown, is capable of vibrating in certain predetermined resonating systems.

To appreciate more fully the conditions involved in molecular vibration and absorption it is essential to consider the nature of the binding between atoms. The atoms constituting a molecule may be held together by either electrovalent or covalent forces. Polar or electrovalent combination is the result of a complete transfer of an electron from one atom to another, and the binding or holding force results from the electrostatic forces of the oppositely charged atoms. Non-polar or covalent combination is the result of sharing of electrons so that they are common to the outer shells of both atoms (Fig. 6.2). The sharing of electrons to form covalent structures may involve two, four, or six electrons, there being no evidence for the sharing of an odd number of electrons such as one or three (*C157*). A coordinate or dative binding is also possible in which both the electrons forming the shared linkage are provided by one of the atoms.

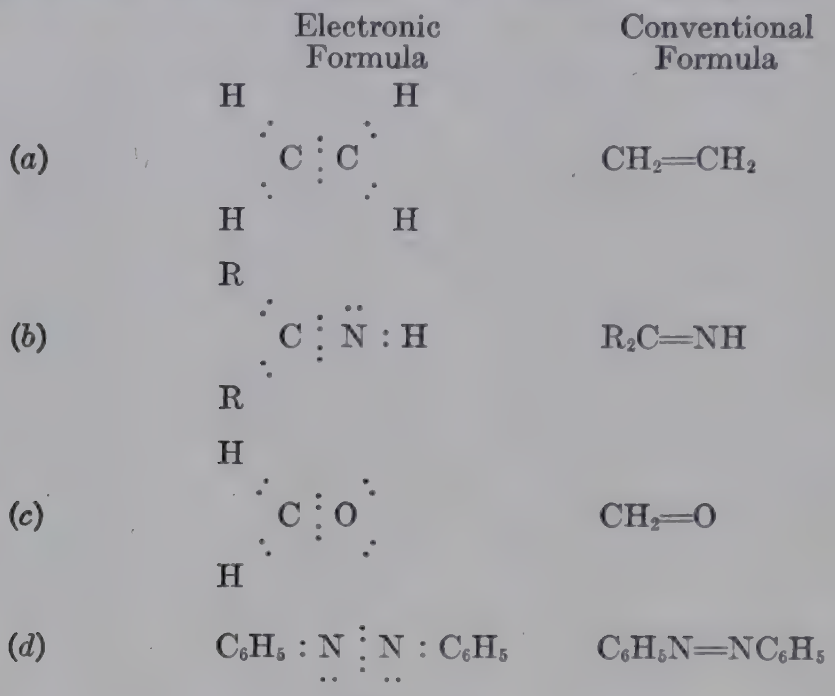


FIG. 6.1

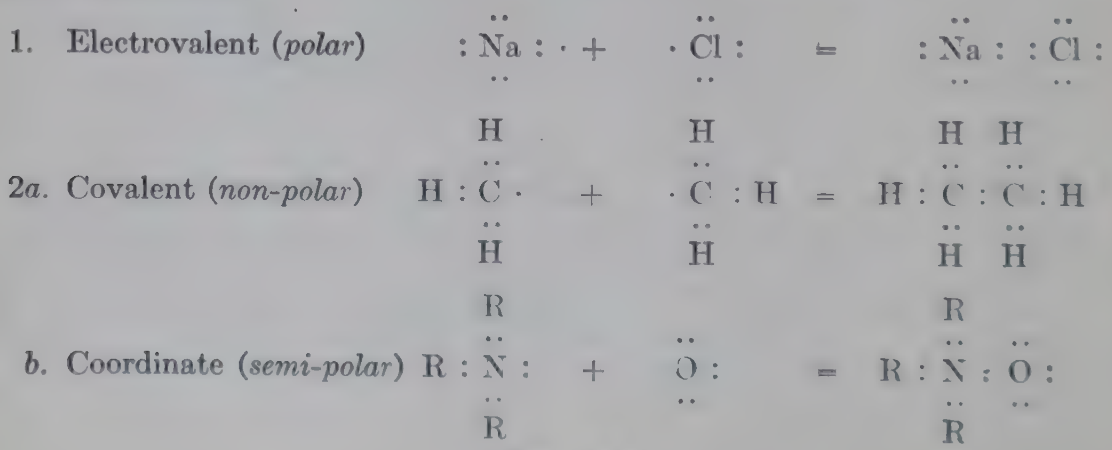


FIG. 6.2

Electrovalence is of little importance with regard to the color of the molecule or vibration between atoms since this ionic binding tends to separate the two parts into complete shells which are not rigidly held in a definite orientation. Covalent and coordinate bonds, on the other hand, involve the direct binding in fixed orientation of the atoms and the ability to resonate or vibrate as a unit. Electrovalent structures may result in a change in the color through an alteration of the covalent forces of one of the atoms involved in electrovalent, covalent or coordinate combination.

Covalent and Coordinate Bonds

Covalent structures result from the furnishing of one electron by each of the atoms to form a pair which is shared by both shells to yield a completed octet, this covalent structure being a normal type of binding. Coordinate structures are formed by the donation of two electrons of one atom to another atom with six electrons to result in completed outer octet shells. This latter type of binding is termed a coordinated bond or valence, the two atoms being designated the donor atom and the acceptor atom. In the combination of halogen acids with ammonia one finds examples of the covalent and electrovalent binding in which the hydrogen is coordinately bound to the nitrogen. Definite rules can be established governing the valence relations in molecular formation. Ionic valence may take place between two atoms, two radicals, or an atom and a radical (Fig. 6.3). It should be noted that in ionic valence involving radicals it is the radical as a whole, and not any one atom, which has the electrical charge and acts as the individual element.

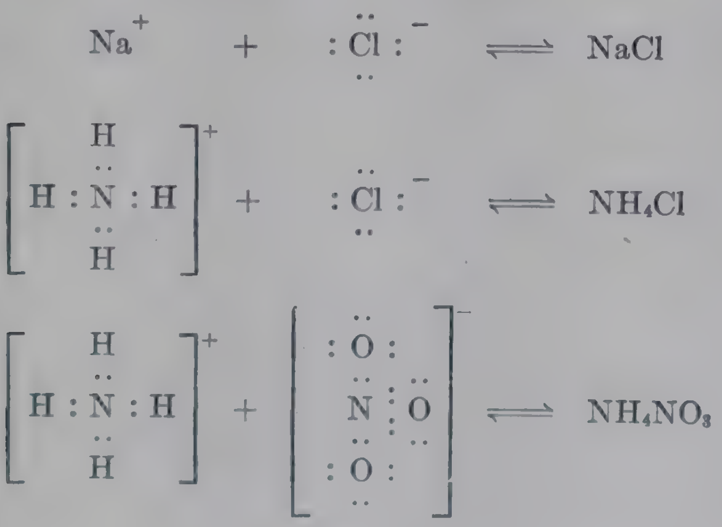


Fig. 6.3

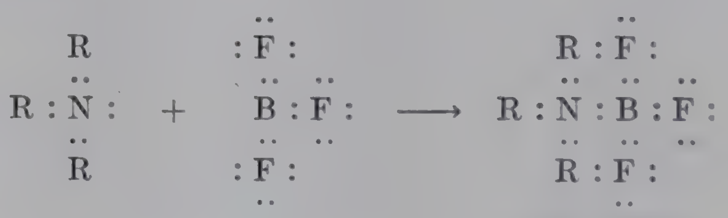
The term *covalent bond* may be used in a broad sense to include both the covalent and coordinate linkages which have been discussed above.

the difference between these linkages depending on whether one or both of the shared electrons come from a single donor atom. If both the shared electrons come from the donor atom the resulting compound will consist of two parts, in one of which (the acceptor) the positive charge will be decreased, and in the other (the donor) the positive charge will be increased. If only one electron comes from the donor atom there will be no change in the charges in the two atoms and a true covalent bond is said to exist.

Double bonds may also be represented as polar or covalent, and in addition there may be a special case where two of the electrons may form a covalent bond and the other two form a semi-polar double bond. In such a compound the oppositely charged portions of the molecule of polar character form a neutral compound which is sometimes referred to as a *polar compound.*

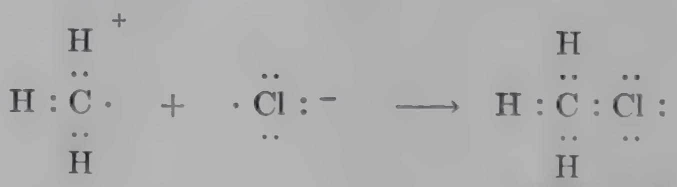
Examples of coordination and covalence are furnished by the combination of NR_3 with BF_3, and CH_3^+ with Cl^- (Fig. 6.4). The arrow serves to indicate the electron shift from the donor to the acceptor atom (A→B), sometimes indicated in the literature by + and − for donor and acceptor, respectively ($\overset{+}{A} - \overset{-}{B}$).

(*a*) Coordinate Bond



$(R_3N \rightarrow BF_3)$

(*b*) Normal Covalent Bond



$(CH_3\text{—}Cl)$

FIG. 6.4
Covalent Bonds

CHROMOPHORIC STRUCTURES

When the electronic structure of a compound can exist in two or more forms of nearly equal energy content, resonance is possible and the relative stability of the two forms will determine the distribution in the equilibrium mixture. Resonance involves the same molecular structure with only a shift in the electronic distribution and should not be confused with tautomerism or dynamic isomerism which involves the equilibrium between compounds of the same molecular formula but different atomic distribution (Fig. 6.5).

The various structural forms arising from this dynamic electronic effect are known as *electromers*, just as the forms arising from dynamic isomerism (tautomerism) are known as *tautomers*. The electromers may be indicated as the neutral and active forms, the neutral ones usually being indicated by the simple bond formulas and the active ones requiring electronic or charge indications. In the single sharing of electrons as in R—OH, the oxygen may act as donor group transmitting an additional electron pair to the C or the R group and thus forcing a redistribution of electron concentration in the R radical. In phenol, the distribution will result in a concentration of electrons at the *ortho* and *para* positions and thus activate these positions towards groups capable of receiving electrons.

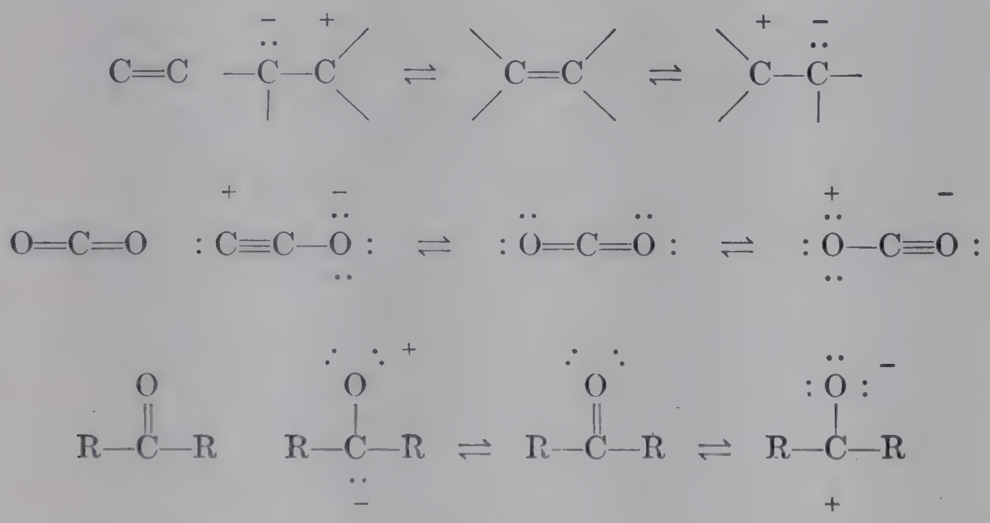


FIG. 6.5

Electromeric Formulas

(*Note:* shared pairs of electrons are indicated by bonds; $^-$ and $^+$ indicate electron gain or loss.)

There are, of course, many ways in which the above effects may be indicated. Another method of presentation involves the electron spacing in the molecule. It may be assumed that in the normal or neutral state the electron pair occupies an intermediate position between the sharing atoms, A : B, but that the active position would involve the shift of the electron pair, e.g., A: B or A :B. Increasing electron concentration on A will induce electron release more readily on those atoms alternate (*ortho*) to A.

Lewis and Calvin (*C123*) have indicated that, in the resonance between electromeric forms as

$$\underset{(1)}{\overset{-}{A}:\quad \overset{+}{B}} \rightleftharpoons \underset{(2)}{A:B} \rightleftharpoons \underset{(3)}{\overset{+}{A}\quad :\overset{-}{B}}$$

or multiple resonators (Fig. 6.11), the extreme forms may not be reached although the center form (2) may be of only momentary existence. A potential energy/nuclear expansion curve may be set up for such resonance (Fig. 6.6), which should yield harmonic frequency values if the potential energy curve follows a parabola.

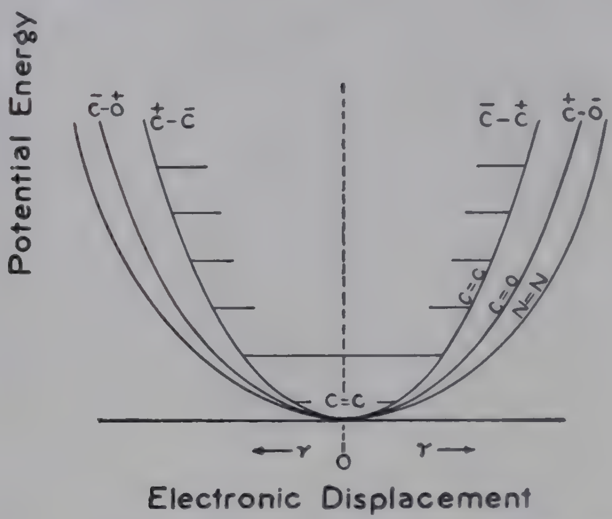


FIG. 6.6. Potential energy/nuclear expansion (electronic displacement) curves. (Lewis and Calvin [*C123*].)

It has been possible through a study of chemical data to calculate the electron distribution between various covalent linkages, the energy, and the refractive index factors for simple coordinated diatomic structures. Reasonably good results are obtained in the prediction of refractive index values from the additive effects of these components, but it must be remembered that these are for a limited number of wavelength values. There is a close tie between refractive index and absorption spectrum, and it would be expected that any such system of prediction which would permit the indication of refractive index for various wavelength values would also serve to predict the absorption spectra of the compound.

An important point to note in this discussion is that electrons in their rearrangement shifts to form electromers move in pairs, and there is no good evidence for the existence of electromers involving sharing of one or three electrons. Single bonds will thus indicate the sharing of two electrons, double bonds the sharing of four electrons, and triple bonds the sharing of six electrons. Compounds involving the sharing of four or six electrons (double and triple bonds) will have these sharing atoms closer together than the corresponding linkage involving the sharing of only two electrons (single bond). Single-bond coupling, especially between like atoms such as the C—C linkage (*a*), will be less readily polarized than the corresponding double bond, C═C (*b*), and triple bond, C≡C linkages (*c*). In the three examples mentioned, the normal and active or polarized structures may be indicated as:

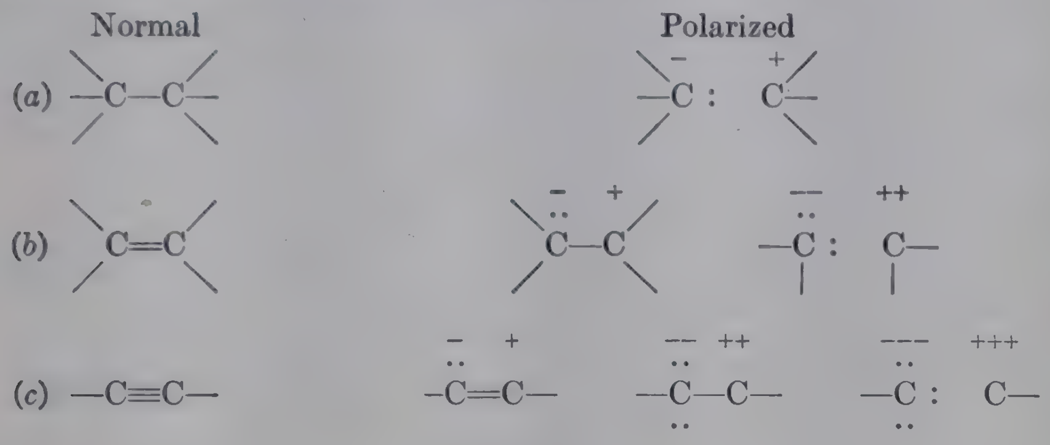


Fig. 6.7
Normal and polarized structures

The electron dots, or + and − signs, or combinations of these to indicate the electronic forms are merely a means for representing the existence of electronic oscillating forms and may not suggest a true picture of the mechanism of resonance.

Chelate Rings

The ability of neutral molecules to donate electrons results in the formation of coordination compounds which are neutral stable structures.

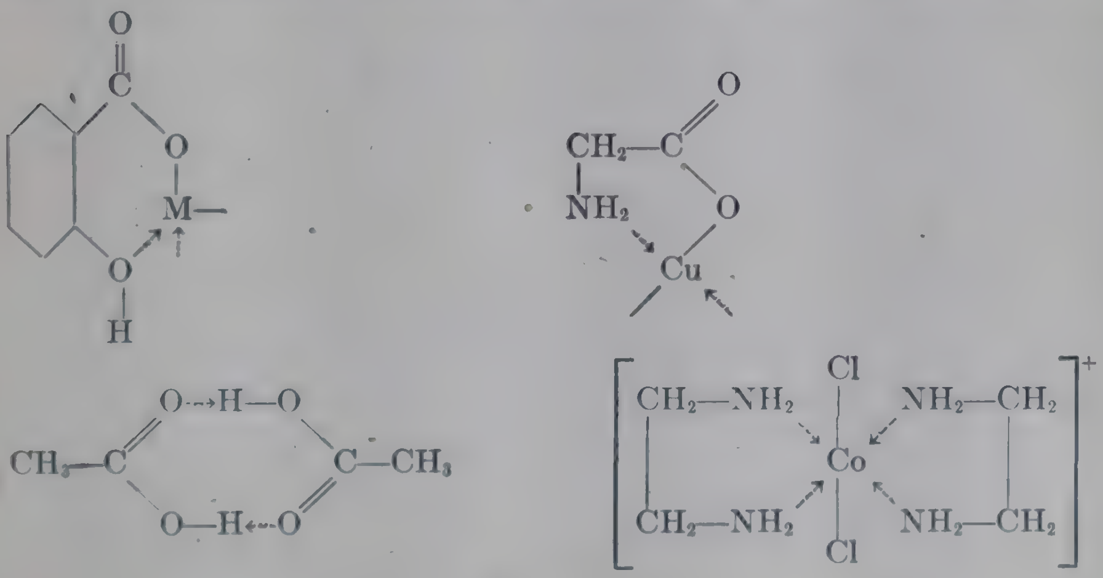


Fig. 6.8

This coordination may involve two parts of one molecule reacting together, or the combination of a donor and acceptor molecule. Where the two parts (donor and acceptor) of the same molecule react together, or there is an interaction between two molecules, each of which contains a pair of donor and acceptor electrons, there will be formed a ring structure which is known as a chelate form (Fig. 6.8).

In so far as chelation is involved with a hydrogen atom we may term the effect a hydrogen bridge. The hydrogen bridge may thus represent the intermediate point in the migration of a hydrogen atom and the equilibrium shift in such a tautomeric equilibrium as the enol-keto tautomerism or benzenoid-quinoid equilibrium (Fig. 6.9).

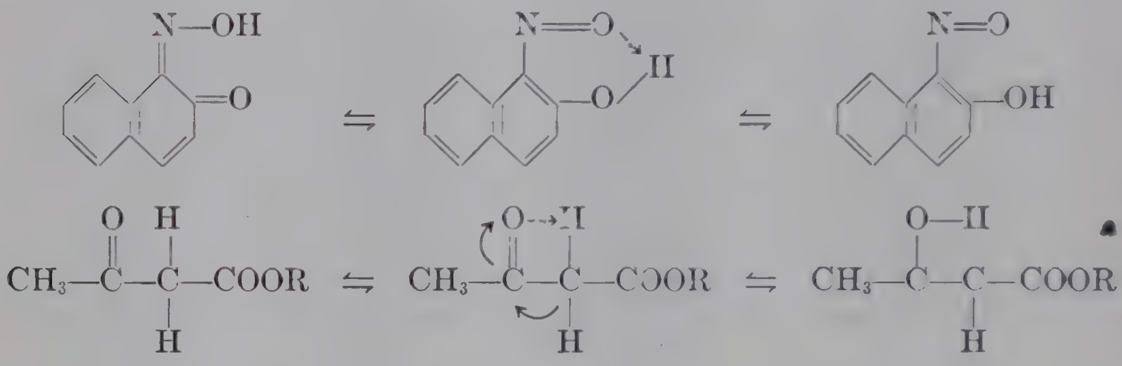


FIG. 6.9

The salts of such enol forms may be ionized in the normal way, or, a chelate structure may be produced through the coordinating properties of the metal salt-forming group.

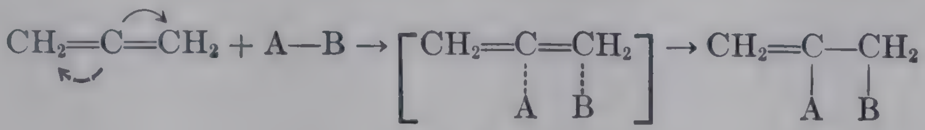
MULTIPLE CHROMOPHORES

The combination of two or more chromophoric groups may result in an increase or decrease in the activity of the entire system. In general, there is an increase in activity when the chromophoric groups are separated by a single bond connection, and an active or polarized form of the neutral molecule will possess two opposite groups at the ends and a neutral portion in the center.

In the simplest type of polyfunctional electromeric system involving two resonating systems, the structural and resonating formulas may be indicated as A—B=C. The ease with which the donor atom or group releases its electrons will determine the degree of equilibrium between the polar and normal form. In a comparison of a series of related A—B=C cases, it is evident that in an acid little if any carbonyl structure is present.

CUMULATIVE CHROMOPHORES

When a compound contains two chromophores which share a central group or atom in such as two double bonds attached to the same atom, A═B═C, the chromophores are said to be commutatively linked. An example of this cumulative coupling is shown in the compound allene.



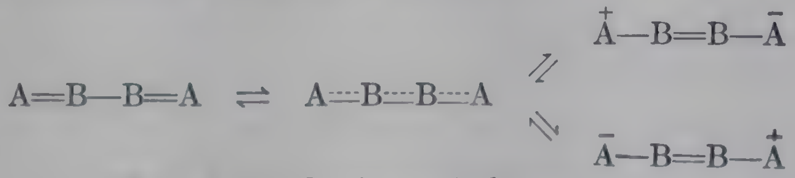
$$CH_2{=}C{=}CH_2 + A{-}B \rightarrow \left[CH_2{=}\underset{A}{C}{=}\underset{B}{CH_2}\right] \rightarrow CH_2{=}\underset{A}{C}{-}\underset{B}{CH_2}$$

FIG. 6.10

Since only one of the two resonating groups is activated, addition will take place either, 1,2 or 2,3 but not 1,3 (Fig. 6.10). Other examples of this type include ketenes in which the oxygen acts as an acceptor from the carbon and in turn as a donor to a reacting substance which adds to the oxygen and adjacent carbon. In general, it may be said that similar resonating groups attached to the same atom neutralize, in part, rather than amplify the resonance of the molecule.

CONJUGATED CHROMOPHORES

When two or more chromophoric systems are joined by a simple covalent linkage involving the sharing of two electrons, the chromophores are said to be conjugated together. The simplest examples, A═B—B═A, involve like groups, although the same effects are noted in mixed systems such as A═B—B═C. In the following examples it is to be noted that electron and polar formulas have been indicated for the chromophoric forms. Either type of formula or a combination of the two forms may represent the resonating condition satisfactorily.



$$A{=}B{-}B{=}A \rightleftharpoons A{\cdots}B{\cdots}B{\cdots}A \rightleftharpoons \begin{cases} \overset{+}{A}{-}B{=}B{-}\overset{-}{A} \\ \overset{-}{A}{-}B{=}B{-}\overset{+}{A} \end{cases}$$

FIG. 6.11*a*. Conjugated chromophores

The conjugated compounds generally show a marked increase in chromophoric activity over that which would be predicted from the sum of the component chromophores.

The resonance energies for some of the conjugated systems (Table 6.1) indicate an increase in energy which is greater than the increase in similar nonconjugated chromophoric groups. By comparison of properties it is to be noted that the 1,3 (conjugated) dienes (double bond or chromophoric groups) are different from the 1,2 and 1,4 dienes in which the

TABLE 6.1

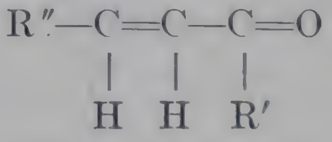
RESONANCE ENERGIES OF CONJUGATED SYSTEMS

(Pauling and Sherman) (*C158*)

1,3–Dienes	8.0	Fulvene	15.0	Naphthalene	74.7
1,3,5–Trienes	16.7	Benzene	37.3	Pyridine	43.1
1,3,5,7–Tetrenes	25.1	Stilbene	94.3	Furan	21.4

double bonds are not conjugated together. The 1,5 diene shows essentially the same properties as the two monoölefins it would form if it were split apart at the third position. Benzene may be considered as a conjugated ring, and much of its stability is ascribed to the alternate double bond—single bond structure.

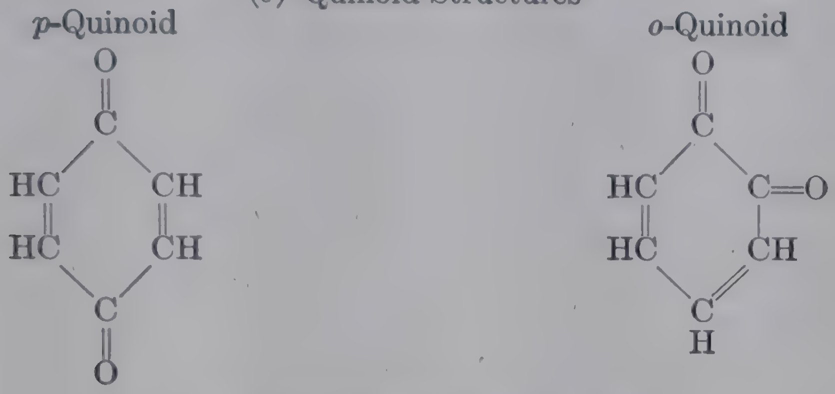
Mulliken, in a series of papers (*C150*), has considered the theoretical aspects of absorption and has indicated that most absorption bands in the near ultraviolet or visible may be characterized by transitions from the normal homopolar (nonionic) (N) to an ionic excited state (V_1) which may be represented as $N \rightarrow V_1$. Theoretical calculations indicate that the intensity of absorption is concentrated mainly in the longest wavelength transition ($N \rightarrow V_1$) although the degree of this concentration will be dependent on molecular character. Mulliken's calculation for the position of the absorption band of octatetraenes was 38,000 cm^{-1} (1140 f) as compared with Hausser's (*C103*) observed value of 33,000 cm^{-1} (990 f) (Fig. 7.10*a* [n = 3]). Brode, Mowry, and Brown (*C48*) confirm the position of 33,000 cm^{-1} (990 f) for the tetraene structure as shown by the absorption of the conjugated isomer of arachidonic acid (Fig. 8.29).

Unsaturated ketones of the formula  $R''\text{—}\underset{H}{C}\text{=}\underset{H}{C}\text{—}\underset{R'}{C}\text{=}O$ belong to the same type of resonating systems, especially when some resonating group occupies the R′ position. Such groups as H or CH_3 inhibit the 1,4 addition reaction which is characteristic of conjugated unsaturation, but directing groups such as C_6H_5, OR, and NR_2 markedly increase the yield when occupying the R′ position and inhibit the reaction when in the R″ position.

As a color-producing and absorbing system, the conjugated systems involved in 1,2 diketones and 1,4 unsaturated diketones are of great importance. In aromatic compounds these are represented as the *ortho* and *para* quinoid resonators (Fig. 6.11*b*).

In the quinoid structures one notes the same effects as in the 1,3 conjugated unsaturated compounds previously described. Acceptor groups such as H— and CH_3— induce activity and absorption when attached to the center of the chromophore, whereas —OR groups (donor) reduce activity and inhibit absorption in the quinoid structure. The —OH and —NH_2 radicals and their derivatives, because of their marked influence on the resonance of a system, when attached in the proper position have been termed *auxochromes*, or color-enhancing groups. The colored forms of nearly all aromatic dyestuffs can be indicated by resonance between certain quinoid and chromophoric forms. The activation of the *ortho* and *para* positions of aromatic compounds through the presence of these groups is another demonstration of this conjugated activity enhancement. On the other hand, such radicals as —NO or —NO_2 activate *meta* positions in an aromatic nucleus, since they are the opposite in electronic properties from the —OH or —NH_2 radicals.

(*b*) Quinoid Structures



(*c*) Aromatic-Quinoid Resonance

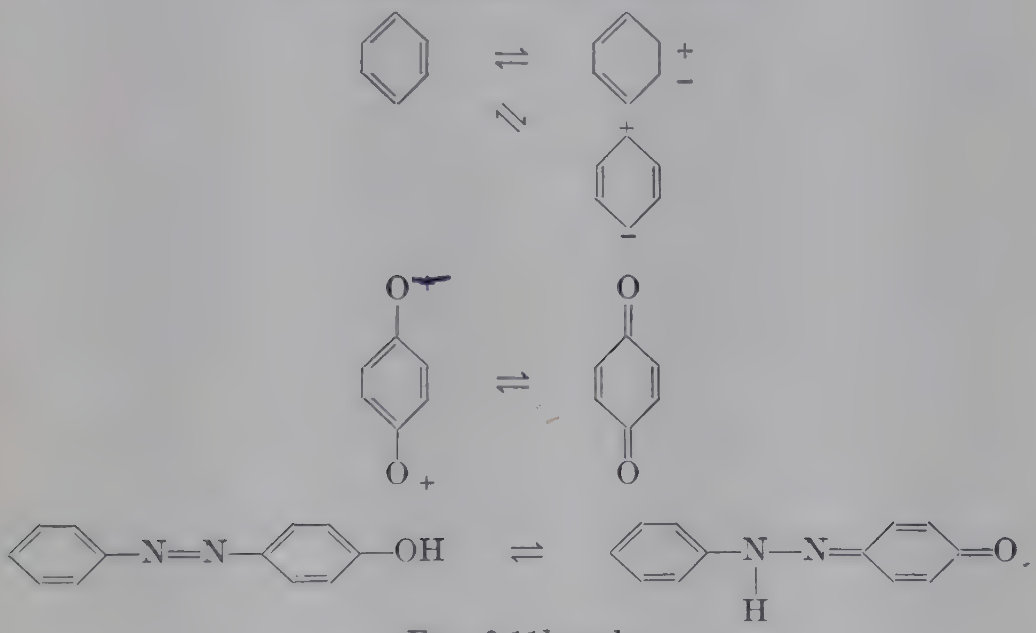


FIG. 6.11*b* and *c*

FREE RADICALS

One other form of resonating system, known as a free radical, should be considered. A free radical, such as the triphenylmethyl, $(C_6H_5)_3C$, violates the accepted chemical principle of even-numbered electrons or shared pairs in a substance capable of separate existence. As might be expected, these radicals are not very stable, and as acceptors they appear to be highly unsaturated molecules. The negative character of the aryl radicals in part offsets the lack of a negative charge sufficient to satisfy the positive proton charge so that the triphenylmethyl chloride is capable of ionization to yield a colored anion. The free radical produced from the triaryl compound is also colored, although not so deeply. The singlet electron in the free radical is distributed over the entire system through the effect which may still be termed resonance. The colored ion represents a positively charged body in which there is a corresponding deficiency of one electron in the outer shell. Like the free radical, this anion has a surrounding group of negative aryl radicals, and there is a tendency to the formation of a resonating system and the corresponding absorption of energy or the production of color, it being an experimentally observed fact that resonating systems absorb more energy than would be normally predicted from the sum of the vibrational energy of their various component units.

THEORETICAL ASPECTS OF ABSORPTION

The theory of the band spectra of simple molecules has been thoroughly studied and reported in other books, and since the nature of this work is such as to be outside the scope of a textbook on applied spectroscopy, only a brief summation of the principles involved will be indicated (*B31*, *A79*, *A50*, *A32*).

Band spectra is the term applied to the spectra of molecules just as "line spectra" is used in the discussion of the spectra of atoms. The observed band spectra of simple molecules can be resolved into discrete lines, but these lines are ordered into groups which are known as bands (see Figs. 2.11 and 2.12). The energy of a transition, as has been previously indicated (page 23 to 27), can be expressed by the equation

$$E_2 - E_1 = E = hv = E_e + E_v + E_r$$

in which the electronic, vibrational, and rotational energies (E_e, E_v, and E_r,) are limited to certain definite values. Like the emission and absorption spectra of atoms, the band spectra of molecules results from absorption or emission of energy, which involves transitions between energy levels, the light energy emitted being the summation of the electronic, vibrational, and rotational energy changes.

ROTATION SPECTRA

The rotational energy change in molecules is very small (order of 0.02 volt), and hence lines due only to rotational energy change will be found in the extreme infrared beyond 25μ (low frequency values.) Pure rotation spectra have been observed only for simple molecules with a dipole moment (such as HCl, HBr, and simple oxides). The frequencies of the lines in the pure rotation band are approximately whole-number multiples of a fundamental frequency. Pure rotation spectra occur at such low frequency values as to be outside the usual available experimental range of observation.

VIBRATION-ROTATION SPECTRA

The vibration spectra produced by transitions in vibration levels (see $v = 1, 2, 3$, Fig. 2.13) and the rotational energy change ($J = 1, 2, 3 \cdots$) combine to yield vibration-rotation spectra, which are sometimes termed vibration spectra, involving a quantum energy change of about 0.1 volt (1.6×10^{-13} erg per molecule) so as to produce spectra in the near infrared region from about 1 to 25 μ. The superposition of rotation spectra on vibration spectra results in a band associated with each vibrational transition (Fig. 10.4). As in rotational spectra it is essential that the molecule be polar in character to produce a resonating form capable of absorption in the infrared.

If the change in rotational level (J) is $+1$ the resulting band portion is known as an *R-branch* and degrades to higher frequencies. The band portion resulting from a rotational level change of J by -1 produces the *P-branch* which degrades to lower frequency values. The vibrational band produced in transitions involving the same state of J in both vibrational levels may result in a third branch known as the *Q-branch* if there is a different moment of inertia in the two states (Fig. 2.14).

As a means of presenting the energy change involved in the vibration-rotation spectra, a potential energy curve may be constructed (Fig. 6.12) in which the ordinate, U, represents potential energy, and the abscissa, r, is the nuclear separation (which may be expressed in angstroms). The two atoms of the diatomic molecule (or two vibration parts of a polyatomic molecule) may be assumed to be vibrating about an equilibrium separation distance, r_0. The vibrational levels are indicated by $v = 0, 1, 2, 3, 4$, etc. As the molecule vibrates (i.e., the two parts move away from or towards each other) it is apparent from the figure that the potential energy will drop as the curve A-B-C is followed and that the molecule will possess maximum potential energy at A (compression) and C (extension).

From Fig. 6.12 it is apparent that, for low values of vibrational quantum number, $v = 1, 2, 3, 4$, etc., the potential energy curve is nearly symmetrical with respect to the equilibrium position and harmonic motion may be expected. For higher values the electrostatic repulsion of the nuclei causes a sharp rise in the slope of the potential energy as the molecule is compressed, whereas the ionic attraction of the elements is reduced as the elements are separated with a resulting flattening of the curve on the side of greater atomic or nuclear separation, and the motion is anharmonic.

Increasing the vibrational energy to higher levels v_x or v_y will result in greater amplitudes of vibration which at level v_z will culminate in a dissociation level which is asymptotic to the potential energy curve. The difference between the potential energy at the lowest (0) vibration level and the potential energy at the v_z level will be the dissociation energy (D) of the molecule. No indication has been given in this vibration-potential energy diagram (Fig. 6.12) of the rotational sublevels, but it should be remembered that between adjacent vibrational levels there are rotational sublevels.

Under normal conditions most molecules exist in the lowest vibrational level, and hence in absorption the vibration band of lowest frequency (*fundamental band*) will correspond to the transition from $v = 0$ to $v = 1$. The transition $v = 0$ to $v = 2$ will result in the first harmonic band, and higher levels will produce higher harmonies.

Electronic Spectra

The atomic emission spectra of the elements involve electron displacement from the central atom, and while similar molecules might be expected to give similar electronic displacement with similar energy changes, and hence spectra of similar frequency, it would be expected that the binding forces operating between the atoms (valence forces) would appreciably affect the energy required to alter the electron orbit or level. As has been demonstrated in the discussion of rotation-vibration spectra there is a superposition of the rotation spectra on the vibration spectra, and hence it is logical that the electronic spectra should involve a superposition of both rotation and vibration spectra.

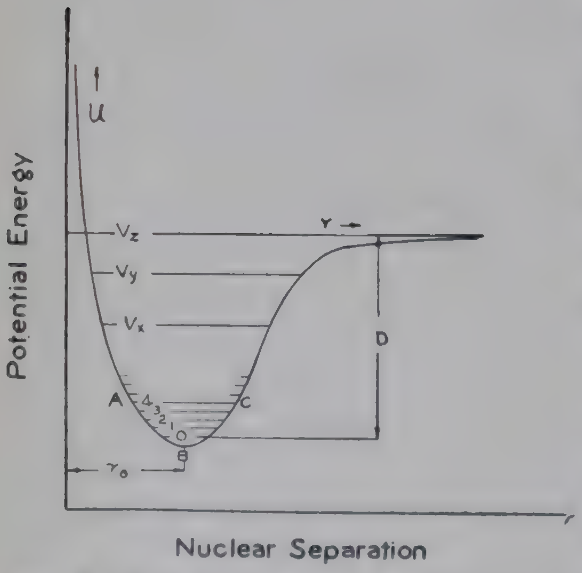
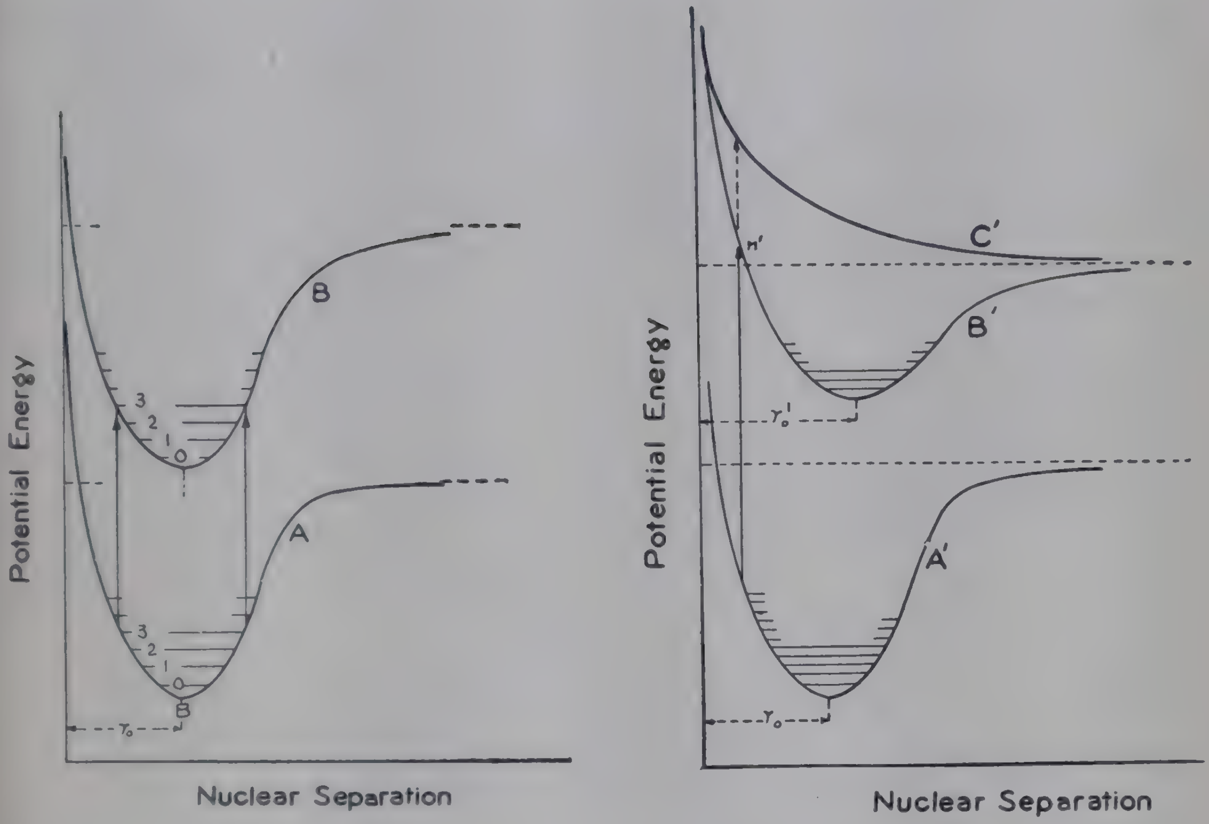


FIG. 6.12. Potential energy/nuclear separation curve.

Electronic transitions will thus determine the general location of the band system. Vibration transition will determine the positions of the individual bands, and rotation transition will determine fine structure of each band. The method used in Fig. 6.12 to illustrate the vibration-potential energy of diatomic (or polynuclear) molecules can also be followed to illustrate electronic transitions as is shown in Fig. 6.13.

The potential energy curve for the normal or ground electronic state of the molecule is represented by *A*, while *B*, *C*, *D*, etc., will represent those for higher electronic levels (Fig. 6.13*a*). Transition from one state to another (*A* to *B*) may take place in symmetrical superposition to produce absorption represented by the energy difference determined by the vertical line connecting to two levels along the potential energy curves. The complexity of spectra produced by the combination of rotation, vibration, and electronic spectra and the influence of adjacent molecules on the molecule so as to alter these factors results in a general absorption band that may effectively resist attempts at resolution. It should be obvious that lowering the temperature to that of liquid air should result in decreased amplitude of vibration and hence a reduction in the number of vibration levels, with consequent sharpening of the absorption bands (Fig. 7.50).



a *b*

FIG. 6.13. Potential energy/nuclear separation curves.

Each electron level will have its own vibration-potential energy curve, and in some cases (Fig. 6.13*b*) the electron shift will result in a shift of the median or average spacing of the resonating parts; if this is sufficient, shifts from higher J values in the lower or ground state (A') may result in dissociation levels in the higher state (n' in B'). Photochemical dissociation will take place in transition from any J value of the ground state if the higher state has a potential energy curve corresponding to C'.

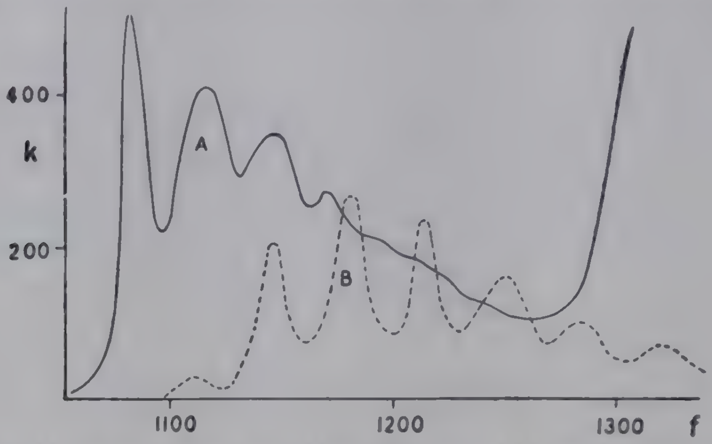


FIG. 6.14. Absorption spectra of p-chlorotoluene (A) and benzene (B). Illustrates symmetrical shifts (A) (intensity concentrated in 0,0 band) and unsymmetrical shifts (B) (intensity concentrated in bands other than 0,0). (Sheibe and Fromel [*B70*].)

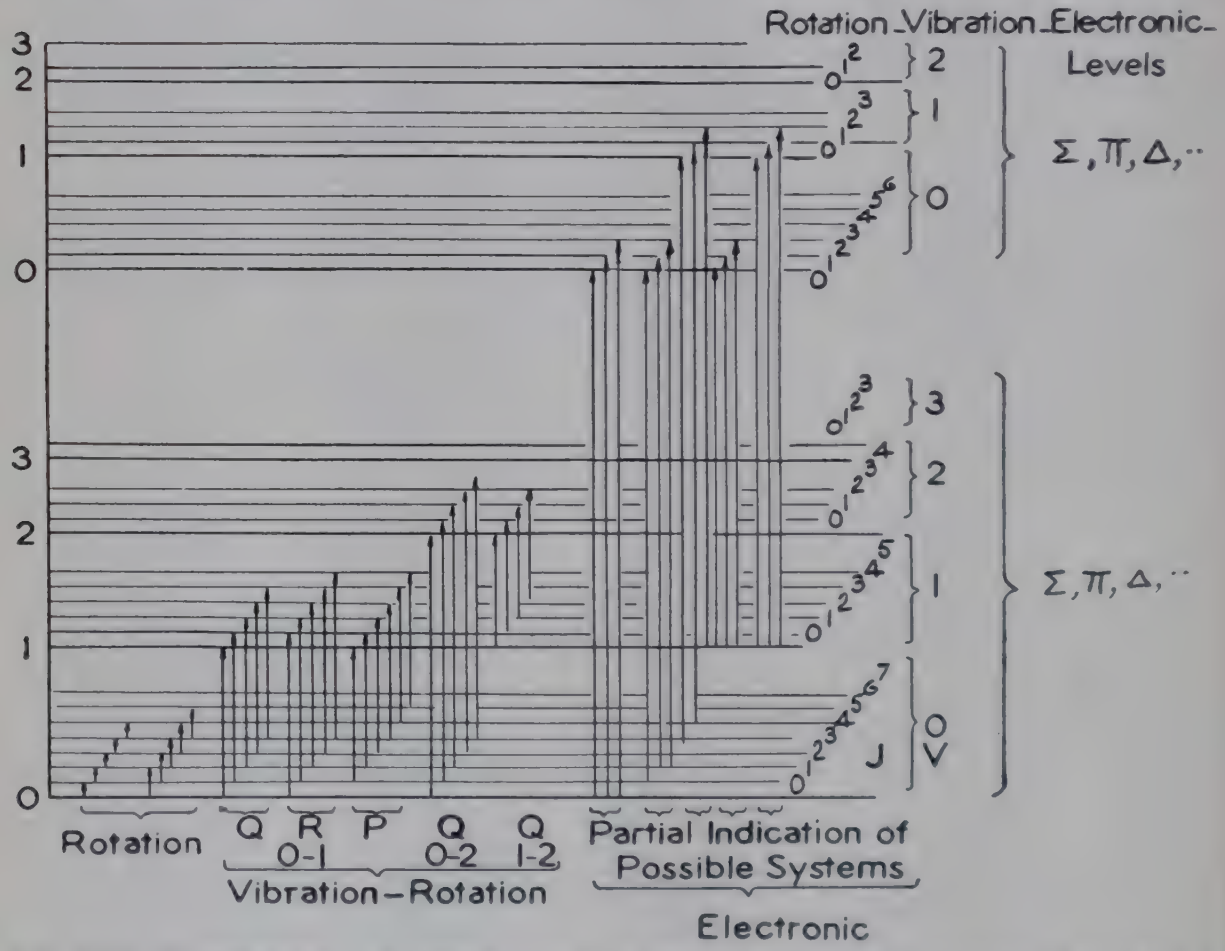

Rotation-Vibration-Electronic-Levels
Σ, Π, Δ, ··
Σ, Π, Δ, ··
J
V
Rotation
Q
R
P
Q
Q
0-1
0-2
1-2
Vibration-Rotation
Partial Indication of Possible Systems
Electronic

FIG. 6.15. Diagrammatic representation of rotation-vibration-electronic levels in a band spectrum.

Dissociation results in a continuous absorption of all radiant energy equal to or greater than the energy required to produce the transition to the dissociation level. Transition in general may be considered to occur principally at the vibrational limits A-C (Fig. 6.12) rather than at intermediate points along the vibrating path of A-B-C since the nucleus will exist for a longer period of time at points of low vibrational kinetic energy (A and C) and will exist only momentarily at intermediate values between A and C (Franck-Condon principle) (*C65*).

LITERATURE

General

J. R. JOHNSON, "Modern Electronic Concepts of Valence" (*B36*).

L. PAULING, "The Significance of Resonance to the Nature of Chemical Bond and the Structure of Molecules" (*B63*).

H. B. WATSON, "Modern Theories of Organic Chemistry" (*B81*).

G. E. K. BRANCH and M. CALVIN, "The Theory of Organic Chemistry" (*B5*).

H. J. LUCAS, "Organic Chemistry" (Chapter 2) (*B53*).

Reference

SKLAR (*C185*), MULLIKEN (*C150*), BROOKER (*C55*), SHEPPARD (*C182*), LEWIS and CALVIN (*C123*), GLASSTONE (*A32*), JEVONS (*A50*), HERZBERG (*B31*).

CHAPTER VII

ABSORPTION SPECTRA (APPARATUS AND METHODS)

Spectrophotometers

The earliest data on absorption spectra reported the absorption ban edges in the observed spectrum (Fig. 7.1). The ease with which it wa possible to dilute the solution or change the cell thickness led to the observation that as a solution was diluted its absorption band was narrowed and reduced in intensity. The plotting of the observed cut-off o extinction values against the concentration or thickness produced th absorption curve for the observed material. The values thus obtaine were a fairly good approximation to our more accurate absorption measurements of today, but were individually characteristic for each observer since the density or extinction point at which the observer was to decid that the band terminated was of a nebulous character. Figure 7.3 show

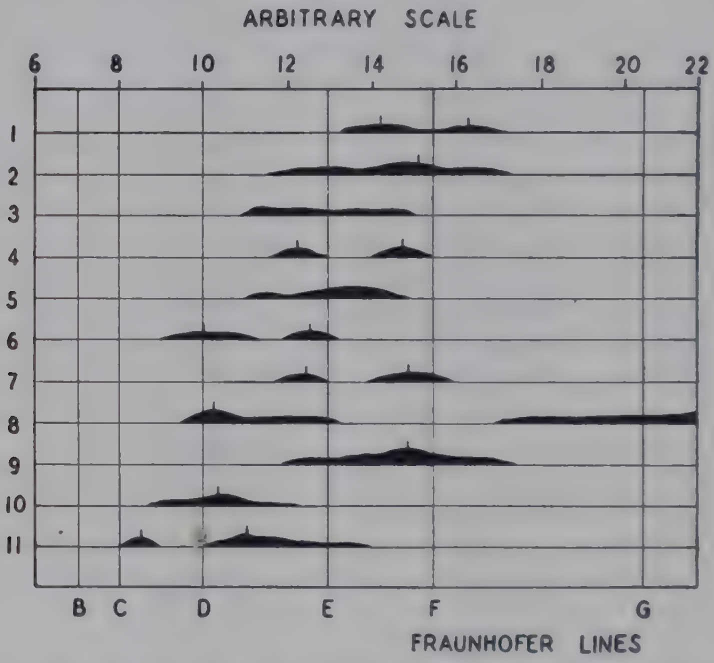


Fig. 7.1. Qualitative indication of absorption spectra (after Formanek [*B19*] and Watson [*B77*]).

1. Orange II. 2. Fast red A. 3. Fast acid fuchsine. 4. Chromotrope 2R. 5. Az fuchsine B. 6. Victoria violet. 7. Poncean 4RB. 8. Diamond green. 9. Congo red. 10. Diamine blue 3B. 11. Azo blue.

examples of data of this type as compared with the same curve (Fig. 7.2, Table 7.1) which has been accurately determined by a spectrophotometric method.

TABLE 7.1

ABSORPTION SPECTRUM OF AZOBENZENE IN ALCOHOL (Brode *C21*)

E	No. obs.	Av. val., f	Av. dev.	Max. dev.	No. obs.	Av. val., f	Av. dev.	Max. dev.	No. obs.	Av. val., f	Av. dev.	Max. dev.
0.00	6	<580	...	...								
.05	4	630	10.0	10.0	4	720	20	30	4	824	2.0	6.0
.10	6	835	1.5	5.0	..	....	...	...	.	....	...	...
.15	1	838	...	...	..	....	...	...	.	....	...	...
.20	5	840	0.4	1.0	..	....	...	...	.	....	...	...
.25	1	843	...	...	..	....	...	...	.	....	...	...
.30	10	845	1.5	3.0	10	1138.4	7.0	18.0	8	1187	11.0	26.0
.35	1	848	...	...	1	1123	...	...	1	1210	...	...
.40	6	849	1.0	2.0	6	1107.5	4.0	8.0	6	1235	4.0	7.0
.45	1	852	...	...	1	1110	...	...	1	1242	...	...
.50	5	855	1.0	2.0	5	1088	5.0	9.0	5	1250	2.0	6.0
.55	2	856.5	0.5	0.5	2	1083.5	0.5	0.5	2	1256.5	1.5	1.5
.60	11	859.4	1.0	4.5	11	1075.5	4.0	6.5	9	1259.5	2.5	5.5
.65	1	860	...	...	1	1071	...	...	1	1264	...	...
.70	6	865.3	2.0	3.7	6	1061	3.0	4.0	6	1266	3.0	4.0
.75	1	870	...	...	1	1054	...	...	1	1270	...	...
.80	6	875.3	1.0	2.7	6	1046	3.0	6.0	6	1273	3.0	3.0
.85	1	877	...	...	1	1043	...	...	1	1285	...	...
.90	6	880.6	1.0	2.4	6	1035.5	2.5	3.5	5	1287	5.0	11.0
.95	1	881	...	...	1	1036	...	...	0	....	...	...
1.00	11	885.3	1.0	2.7	11	1026	3.5	7.0	7	1306	7.0	16.0
1.10	4	889.8	0.2	0.8	4	1013	3.0	5.0	1	1325	...	...
1.20	4	898.5	0.8	1.5	4	1000.5	3.0	7.5	1	>1380	...	...
1.30	4	900	0.2	1.0	4	990	4.0	6.0	.	....	...	...
1.40	7	908	4.0	9.0	7	981	4.0	7.0	.	....	...	...
1.50	12	927	7.0	17.0	12	965	8.0	15.0	.	....	...	...

Concentration, 3.3 cg. dissolved in 100 cc. of 95 per cent alcohol; cell thickness, 0.5 cm.

From the work of Lambert and Beer we know the relationship between absorption and thickness and that between absorption and concentration. These relationships may be expressed as

$$E = \log \frac{I_0}{I} = kcd$$

where E = extinction or the logarithm of the ratio of the incident to the transmitted light. Lambert's law more specifically indicates that the extinction, E, is a linear function of d, the thickness of the solution or solid, and Beer's law that the extinction is a linear function of the concentration, c, of the material. It therefore follows that the intensity, I, which is transmitted by the solution will vary inversely as the logarithm of the concentration or thickness, so that the logarithm of the thickness or concentration will appear as a linear function of the extinction. A number of collected tabulations or figures have been made of organic and inorganic compounds, based on the variation of thickness or concentra-

tion, or the introduction of a neutral gradient wedge (*B56*, *B28*)
7.4). See also Fig. 12.46 for apparatus. In some cases a rough visual
was drawn by the observer from his opinion as to relative brightn

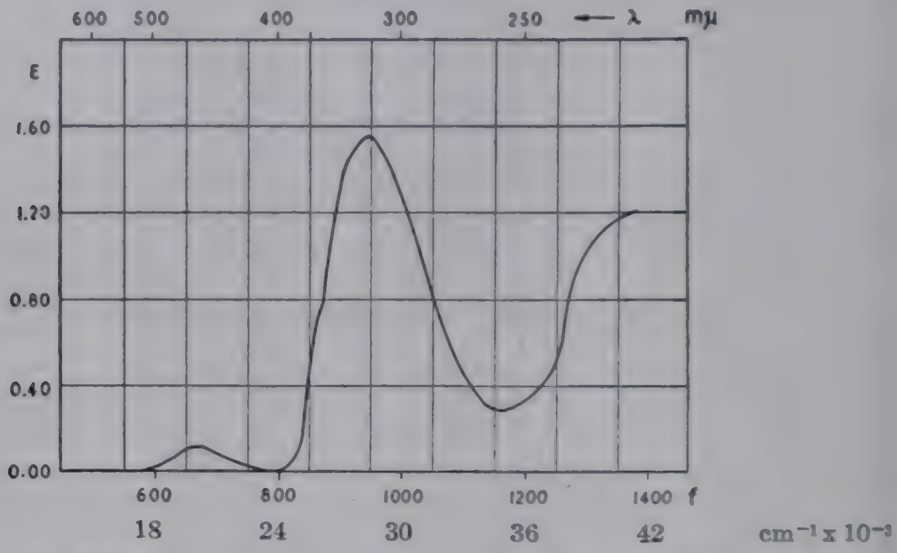


FIG. 7.2. The absorption spectrum of azobenzene (*C21*).

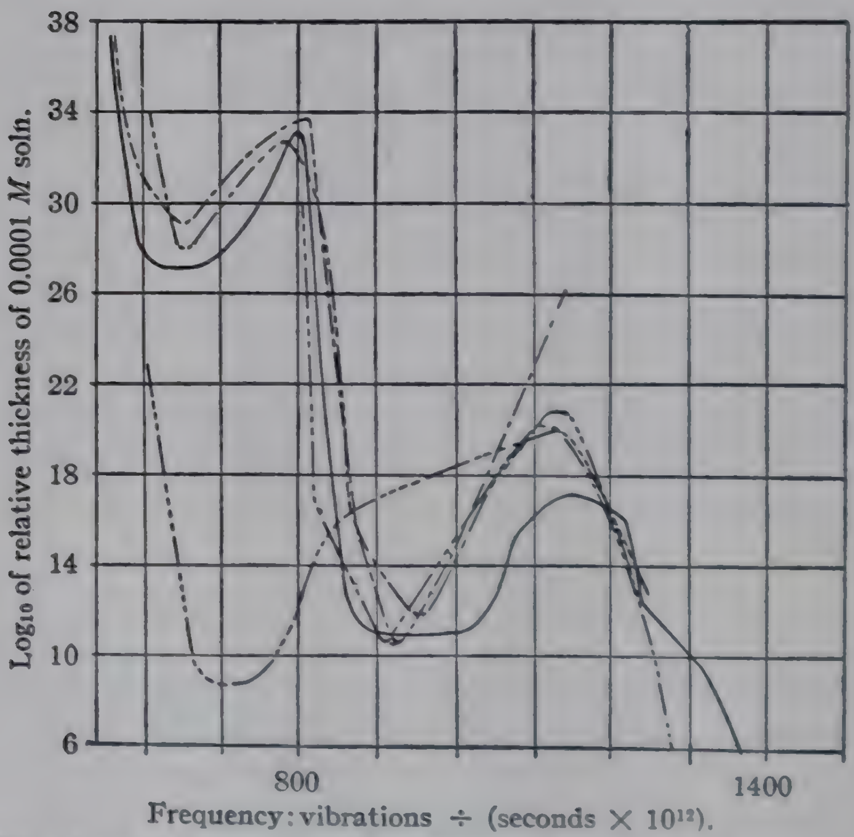


FIG. 7.3. The absorption spectra of azobenzene in alcohol as determined by
and Tuck (solid line); Baly and Hampson (one dot); Hantzsch (two dots);
and McCleland (three dots), and in concentrated hydrochloric acid by Tuck
dots), (*C21*).

the spectrum or density of absorption. In others a more exact dete
nation was made by a series of dilutions and an attempt to match t

at a given density. The Baly tube, a cell of adjustable length, was found to be very useful in the preparation of absorption data of this type. (Fig. 7.5).

The next improvement in instrumental construction was the optical projection on the slit of the spectroscope or spectrograph of two images, that of the original beam and that of the beam after passage through the solution under investigation. Among the various methods are the use of a biprism (*a*), Albrecht rhomb (*c*) (sometimes called a Hüfner rhomb), Brace prism, Luhmmer-Brodhun cube (*b*), two right-angle prisms (d_1 and d_2), and polarizing prisms (*A23*) (Fig. 7.6). By means of such devices it was possible to compare the total absorption of the solution, or, with a cell in both beams, to compare the spectral absorption intensities of two separate solutions. In the comparison of the absorbing solution against the original light source it is obvious that the intensity of the unabsorbed beam will always be as great as or greater than the intensity of light from the partially absorbed beam. The next improvement was a means of reducing the intensity of the comparison beam, by the introduction of some absorbing material into this beam. This absorbing material must have a uniform absorption for all wavelength values and

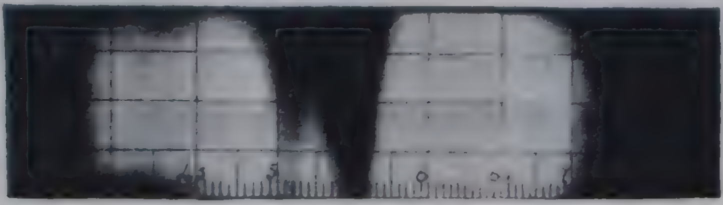


FIG. 7.4. Wedge spectrogram of Rose Bengal 5B 1/4000 (Mees [*B56*]).

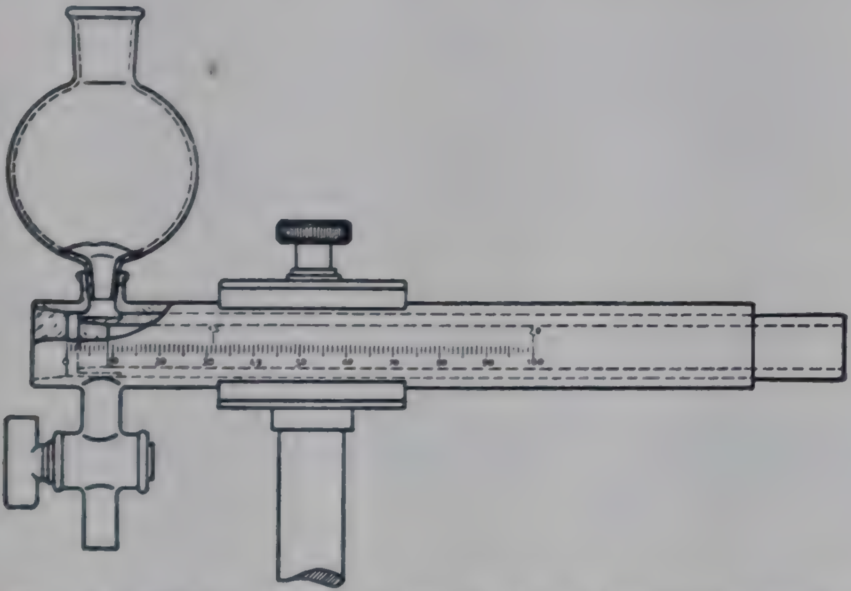


FIG. 7.5. Baly tube for variation of cell thickness (Zeiss).

should, if possible, be adjustable in density over a series of differ values which in turn could be standardized in terms of absolute tra mission. A double-jaw slit as a mechanical means of light reduction h been tried with reasonable success (*C200*). The combination of spect scope and diaphragm-slit in one piece was not found to be very practica so the mechanical slit or diaphragm devices were separated from th spectroscope slit. Mechanically operated devices on present-day m chines include the rotating sector, the Judd Lewis vane photometer, tl Spekker diaphragm photometer, wire or ruled quartz screens of know transmission value, and partly silvered or aluminized filters. Among tl most satisfactory types of photometer devices for matching the tv

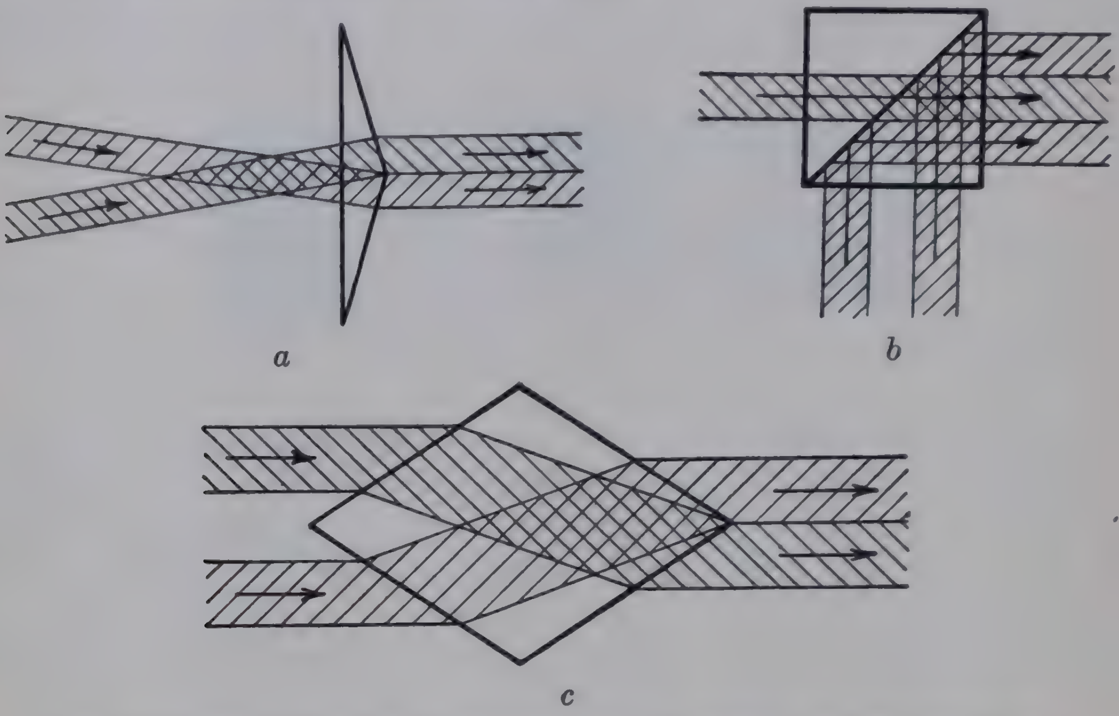


FIG. 7.6. Optical devices to bring two light beams into juxtaposition.

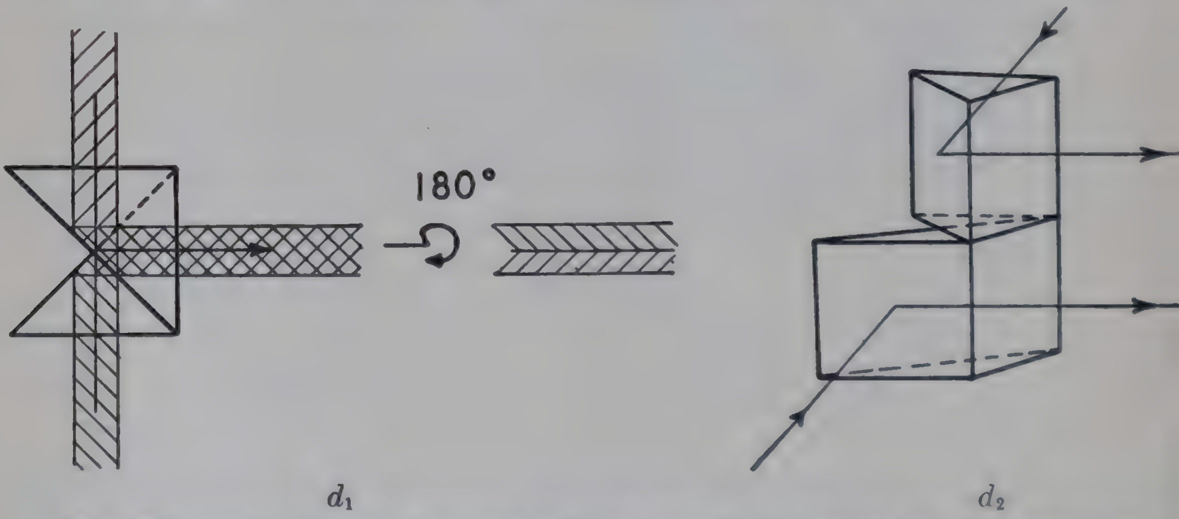


FIG. 7.6 (*cont.*). Optical devices to bring two light beams into juxtaposition.

beams are those applying the polarizing principle. In such instruments the two beams from the solvent and solute are polarized in opposite directions and brought in parallel through a second (analyzer) polarizing prism. This analyzer prism upon rotation alternately extinguishes and transmits the two beams with a match of the two beams somewhere between each of these extinction angles. The Hilger-Nutting, Bausch and

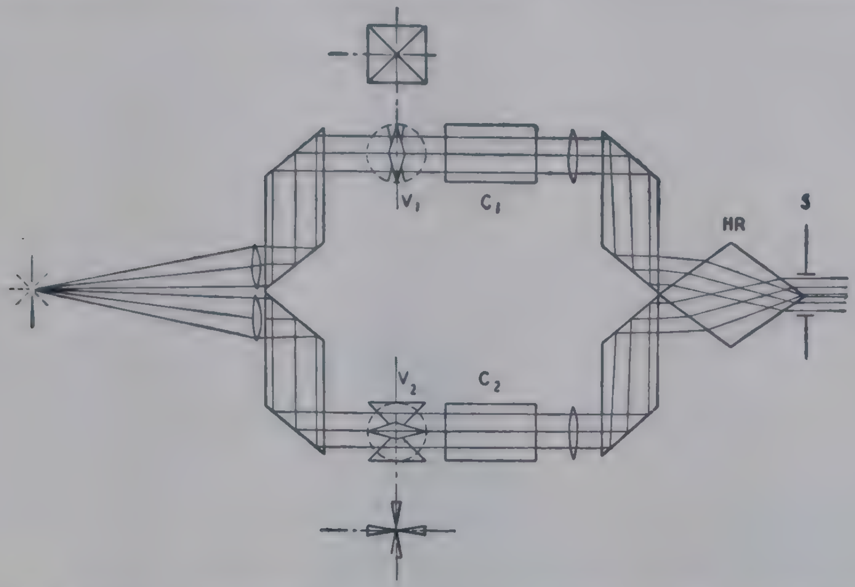


FIG. 7.7. Judd-Lewis photometer (mechanical-vane type). v = vanes; c = cells; HR = Hüfner rhomb (*B44*).

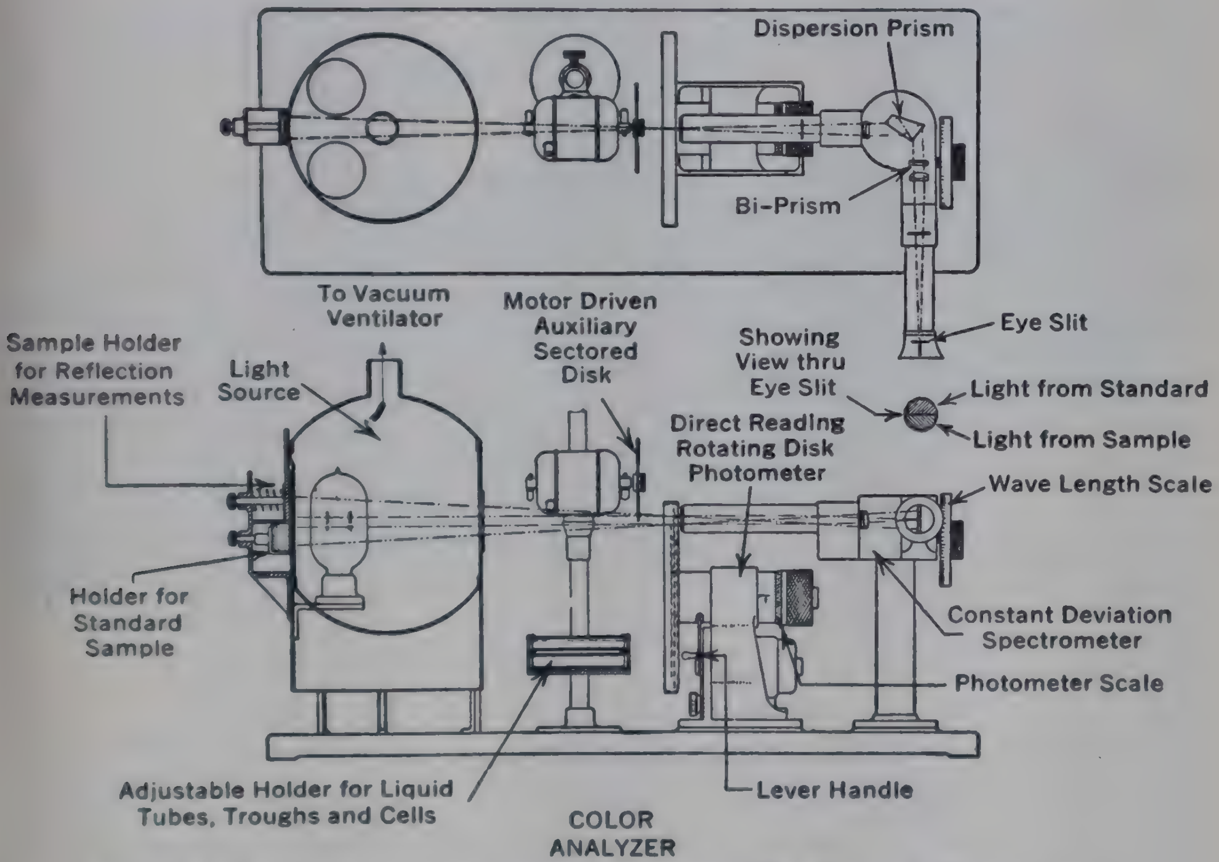

Dispersion Prism
Bi-Prism
To Vacuum Ventilator
Motor Driven Auxiliary Sectored Disk
Eye Slit
Sample Holder for Reflection Measurements
Light Source
Showing View thru Eye Slit
Light from Standard
Light from Sample
Direct Reading Rotating Disk Photometer
Wave Length Scale
Holder for Standard Sample
Constant Deviation Spectrometer
Photometer Scale
Adjustable Holder for Liquid Tubes, Troughs and Cells
Lever Handle
COLOR ANALYZER

FIG. 7.8. Rotating sector spectrophotometer (Keuffel and Esser) (*C15*).

Lomb visual instrument, Jobin and Yvon, König-Martens, and Hard spectrophotometers all apply this photometer principle. Diagrams an photographs of certain of these instruments which represent the typ indicated above are given in Figs. 7.7, 7.8, and 7.9 (see also Figs. 7.2 and 12.28).

The Keuffel and Esser instrument is of interest in that it uses a high speed sector for visual determination, depending on the inability of th eye to distinguish a rapid flicker of high intensity from a continuou weaker intensity. This high-speed sector is adjustable while running so that the instrument becomes as simple to operate as the rotating-prism types. The Hilger sector photometer, the Bausch and Lomb ultraviolet photometers, the Zeiss photometer, the Gaertner photometer, and many others employing photographic methods of recording are constructed with rotating sectors as a means of reducing the intensity of one beam as compared with the other, and the final image on the photographic plate is produced by a series of intermittent exposures of variable length.

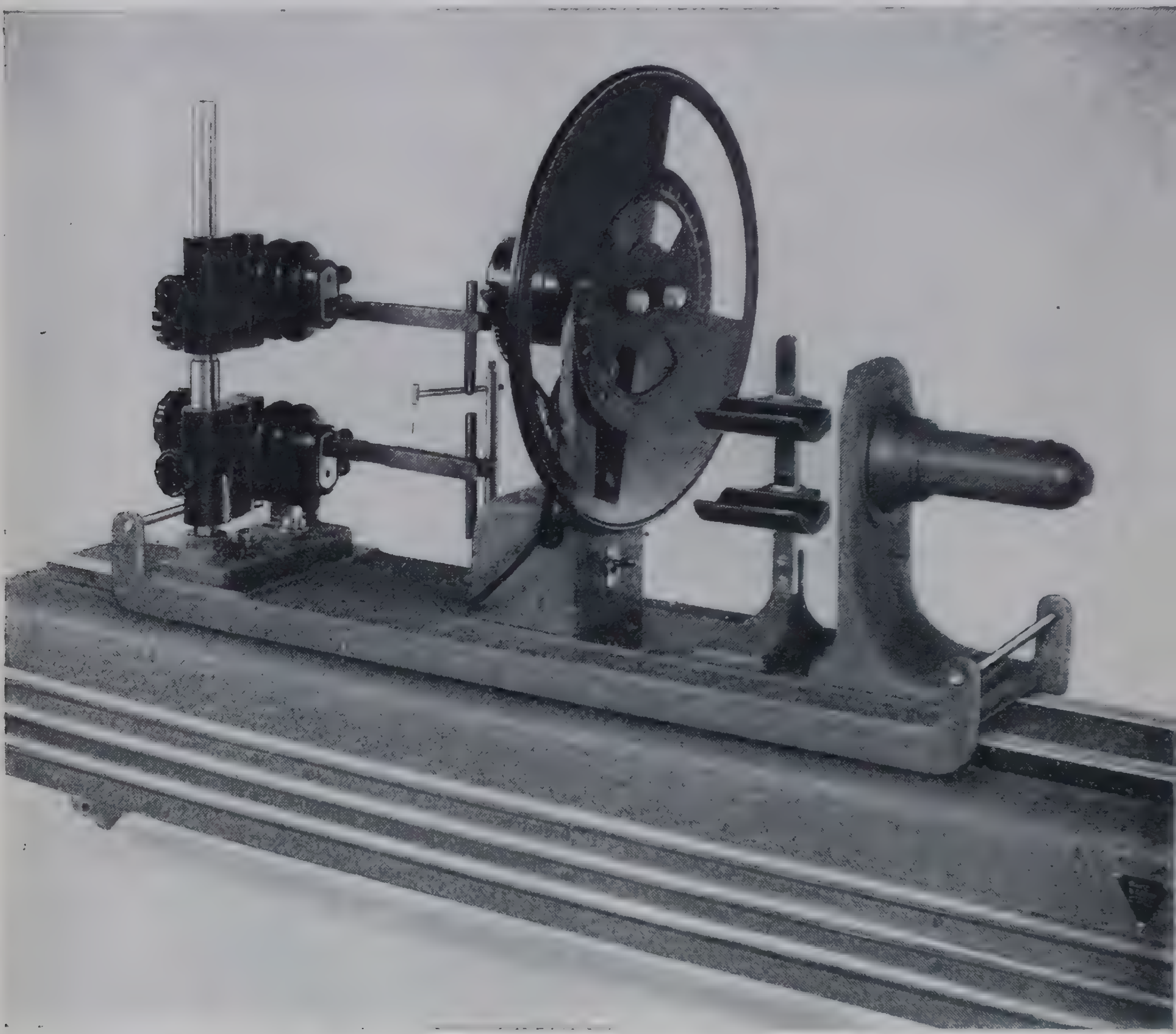


FIG. 7.9. Ultraviolet sector photometer (Bausch and Lomb).

On the assumptions that the photographic process (see section on photography, Chapter XIII) does not involve an inertia at the start of exposure, or continuation of action after exposure, and that the density of the image is a linear function of the product of the intensity of light and the exposure time, the substitution of sectors for diffusing screens, wedges, or polarizing devices is quite acceptable. For a time it was thought that the sector method had quite an appreciable error due to variation in these factors, but it has been shown (*C144*, *C145*, *C171*, *C176*, and *C203*) that the possible error is well within the experimental error of the other methods. So far as the intermittency effect on the photographic plate is concerned, O'Brien (*C153*) has shown that if the number of intermittencies or light increments which are to make up the total energy affecting the silver halide is greater than 150 to 200 no observable error will be involved in the sector method within the accuracy with which the other variable factors can be controlled or measured, such as the cell thickness, the concentration, the position of the diffuse edges of the absorption band (matching the negative), or the setting of the sector values.

The simplicity of the sector and diaphragm methods is one of their greatest advantages, and, even though there are a number of optical methods of ultraviolet photometry, these methods are still the most practical and most widely used procedures. In the simplest form a single rotating sector is placed in the comparison beam and the sample to be measured is placed in the other beam. Both beams are brought into juxtaposition at the slit by one of the optical methods which have been suggested (Fig. 7.6), and a series of photographs or observations is made with different settings of the sector opening. The sector opening can be graduated in degrees, percentage, or extinction (see Table XI in Appendix for the relation among these factors). In many instruments two sectors are used (Hilger, Bausch and Lomb), although in some a single sector with two separate segments is employed (Bausch and Lomb, Gaertner, Keuffel and Esser) and in other instruments only a single sector is employed (Zeiss). (Fig. 7.9). Table XI, "polarizing angle 45° extinction" column, is intended to apply to the optical method, in which a prism angle of 45° yields two fields of equal intensity, and at either 90° or 0° one or the other of the two beams is extinguished. The effective angle is thus 45°, which can be graduated in 100 divisions to read in percentage, or in the negative logarithm of the percentage to yield the extinction value.

$$E = 2 \times \log \tan \theta$$

($4 \times \log \tan \theta$ if instrument has match points every 45° instead of 90°)

In sectors which are composed of two 90° segments or one 180° segment it is necessary to expand the percentage graduation system to 10 divisions for the total opening or the corresponding extinction values If no sector of similar maximum opening is used in the sample beam i will be necessary to graduate the sector on the basis of 360° rather tha 180° total opening. Most sector instruments use two sectors, one in eac beam, with a sector in the sample beam of constant opening (usually on 180° or two 90° openings), and the other sector in the solvent or comparison beam which is adjustable to a maximum opening equal to th constant opening of the solution beam sector.

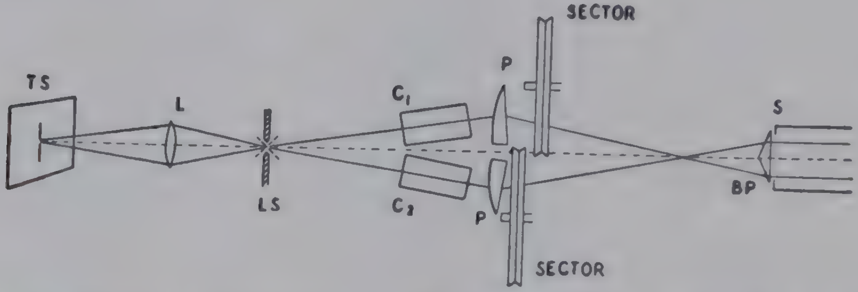


Fig. 7.10. Hilger sector photometer. (See Chapter XII, Exercise 9, for descriptio of parts.)

Not many of the modern sector or diaphragm instruments are constructed with both sectors adjustable; this, however, is quite advisable s that the sample and comparison beams may be interchanged and thu eliminate possible instrumental errors due to alignment or graduation Since the intermittency error becomes negligible with sufficient interruptions of the beam it often is desirable to remove one sector entirel from the sample beam, thus doubling the amount of light transmitte (from 50 to 100 per cent) and producing a condition similar to the transmission of diaphragm instruments. This can be accomplished in th Hilger instrument by removing the driving belt for one sector, or in th Keuffel and Esser instrument by lowering the sector drive. This chang from 50 to 100 per cent involves an increase in the extinction values o 0.3, i.e., 0.3 should be added to each value used to get the true extinction. This change permits higher values to be set with greater accuracy and shorter exposures are required for equal spectrum density (e.g., wit the sample sector stopped and left open, a setting of 1.5 *E* on the comparison sector will give a value equivalent to 1.8 *E*).

A special type of sector photometer which deserves mention and whic promises to speed up the procedure of photographic spectrophotometr has been devised by O'Brien (*C153*). This instrument uses a multipl Luhmmer-Brodhun cube with ten to twelve alternate contact faces o strips (Fig. 7.11), so that over a slit height of about 15 mm there will be that many separate strips in the spectrogram coming alternately from the transmitting and reflecting prism faces. In front of the transmitting face is placed a logarithmic or step sector, and in front of the reflecting face is placed a right-angle prism cell, so that both faces are illuminated from the same source. In this manner it is possible to take the equivalent of ten to twelve separate photographs at different extinction values in one operation. There is no particular restriction on the cell size or thickness so long as the entire prism face is illuminated. It is essential in this

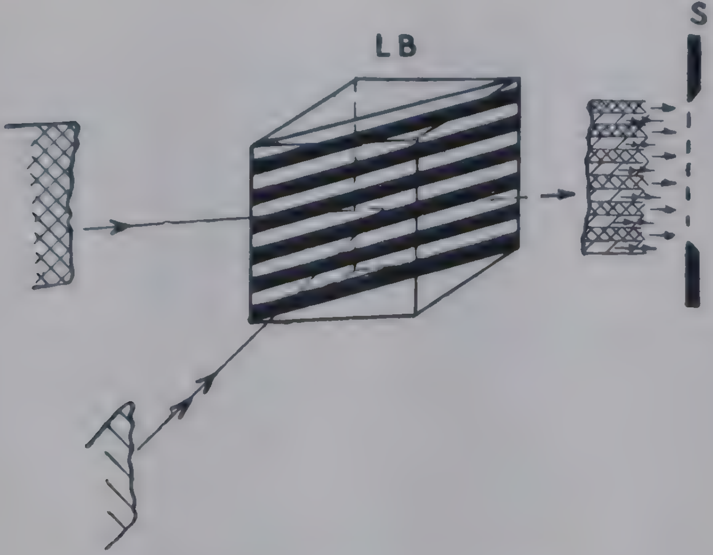


FIG. 7.11. O'Brien photometer cube.

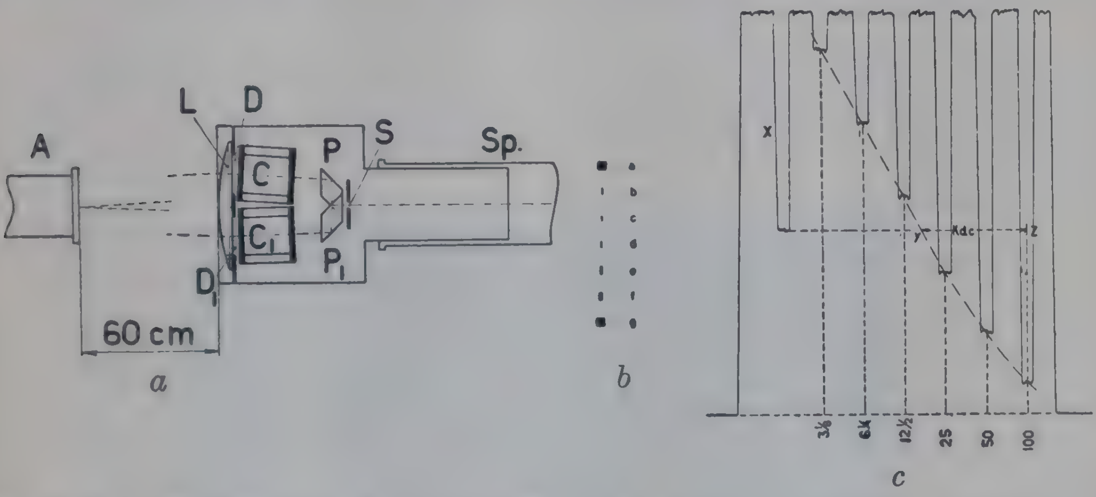


FIG. 7.12. *a* Multiple slit photometer; *C* and C_1 indicate solution and solvent cells illuminated by light source (*A*) through lens (*L*) which focuses on the spectrograph prism. Rhombs (*P*) and (P_2) project beams through slit (*S*).

b Step slit.

c Microphotometer record of spectrum intensities (measured at right angles to dispersion direction) showing method of extinction determination (Moll, Burger, and Rerchert—Kipp and Zonen).

method to have an even and uniform illumination covering all of the tw prism faces.

A somewhat similar device in which a number of photographs a taken simultaneously is available in the form of the Hilger echelon cell (*C198*) in which the variation in extinction is accomplished by changin the thickness of the solution in a series of logarithmic steps. A sector i used in front of the comparison beam to reduce the transmission to known extinction values (Figs. 7.13 and 7.14). The notched echelon cell provides a very convenient and rapid method for spectrophotometri

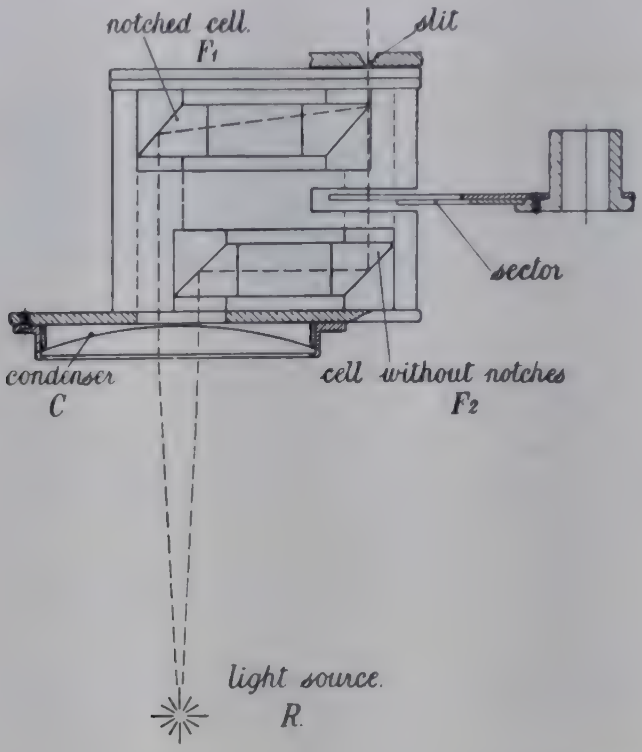


FIG. 7.13. Optical system for echelon cells (Hilger).

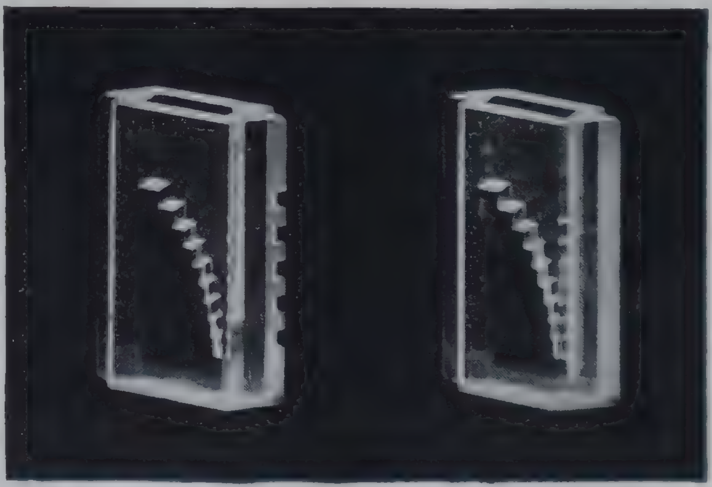


FIG. 7.14. Echelon cells (Hilger).

analysis, but is limited to low extinction values by the maximum cell thickness. In a single exposure ten photographic pairs can be obtained representing an extinction change from 0.0 to 1.0 in steps of 0.1 *E*.

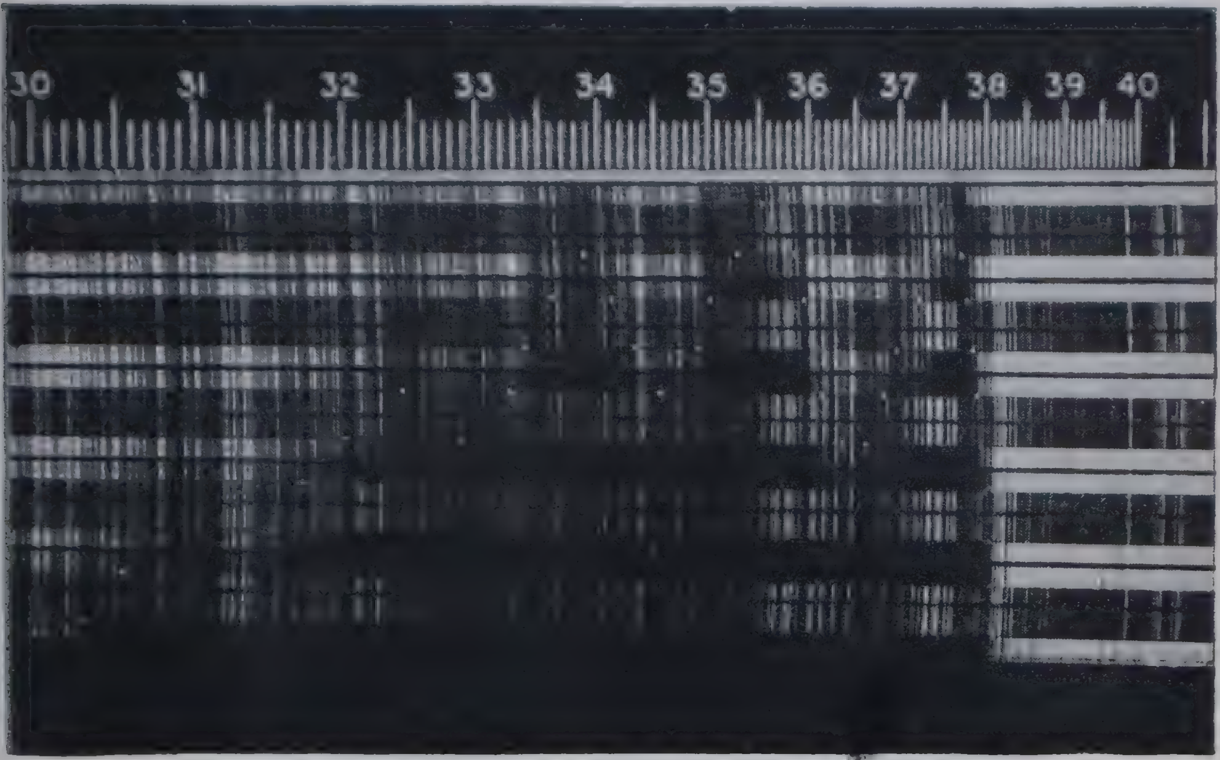


FIG. 7.15. Photograph taken with echelon cells.

HILGER SPEKKER PHOTOMETER

The rotating sector method as developed by Twyman of Adam Hilger has been the means for producing most of the quantitative data which are available today. To overcome some of the possible disadvantages of, and improve upon, this excellent contribution in apparatus development, Twyman has recently designed a diaphragm photometer known as the Hilger Spekker photometer (*C197*). In this instrument (Fig. 7.16) it is not necessary to take the light from as great an angle of view as is necessary in the Hilger sector photometer since the beam is spread by two quartz rhombs. The beams are made approximately parallel by means of the lenses L_1 and L_2, and then they pass through a fixed diaphragm and an adjustable diaphragm *D*. The adjustment of this rectangular diaphragm is effected by a micrometer screw with an indicating drum and guide, *E*. The drum is graduated in extinction values, and the diaphragm is so constructed that the higher extinction values can easily be set with accuracy. The final observations are based on the relative transmission of the fixed and adjustable diaphragms, and it is therefore essential that the cells C_1 and C_2, for the solution and solvent respectivel should be of such a diameter that neither one masks any part of th optical beam. The two beams are brought to a focus on the slit of th spectrograph through the lenses L_3 and L_4 and are brought into juxt

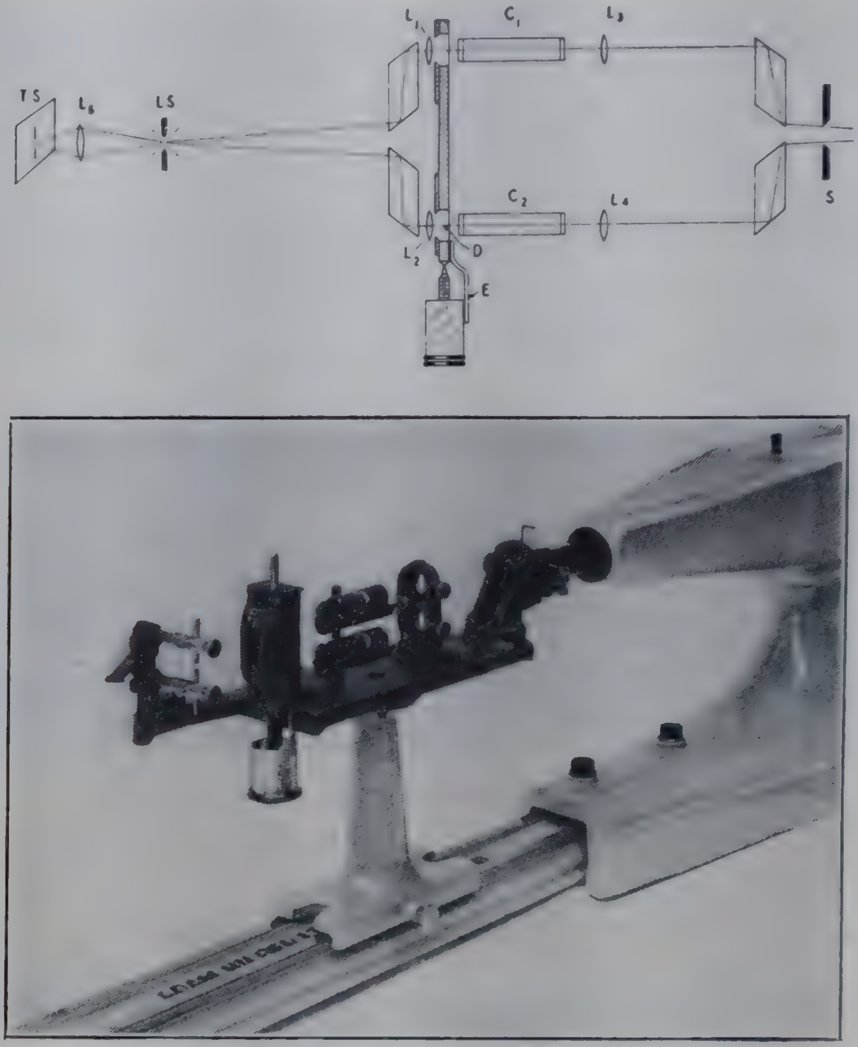


FIG. 7.16. Hilger Spekker photometer.

position at the slit of the spectrograph by the second pair of quart rhombs.

Twyman has pointed out that this instrument has certain advantage over his previously designed sector photometer in that the absence o motor-driven sector parts and interruption of the light beam remove possibility of synchronism of the light-source fluctuations with the perio of the sector so as to produce erroneous results. This error is not ap parent in the use of d-c light sources or high-frequency a-c light source such as are found in the underwater spark or a 500-cycle a-c hydroge discharge tube. As has been pointed out in this discussion, the advantag claimed for the Spekker photometer of an increase in intensity by a facto of 2, due to the stoppage of the constant beam by a 50 per cent sector, i not a valid argument in favor of the diaphragm instrument since the constant sector can easily be stopped or removed from the path of the solution beam, and in fact some of the quantitative spectrophotometer methods use but one sector, namely, that in front of the solvent cell (Zeiss method).

The outstanding advantages of the Spekker instrument are the ease of making settings without the necessity of stopping moving parts, and the greatly increased accuracy in making extinction settings, especially at high density values. The rhomb system of light gathering so as to take the two beams from nearly the same direction from the light source permits the use of a point of concentrated light source. To permit the illumination of both rhombs where the light source is too highly concentrated or directed, as in the hydrogen discharge tube, a rocking mirror device has been designed to direct the beam alternately to the two rhombs (Fig. 7.17). This alternating or rocking mirror illumination reflector is subject

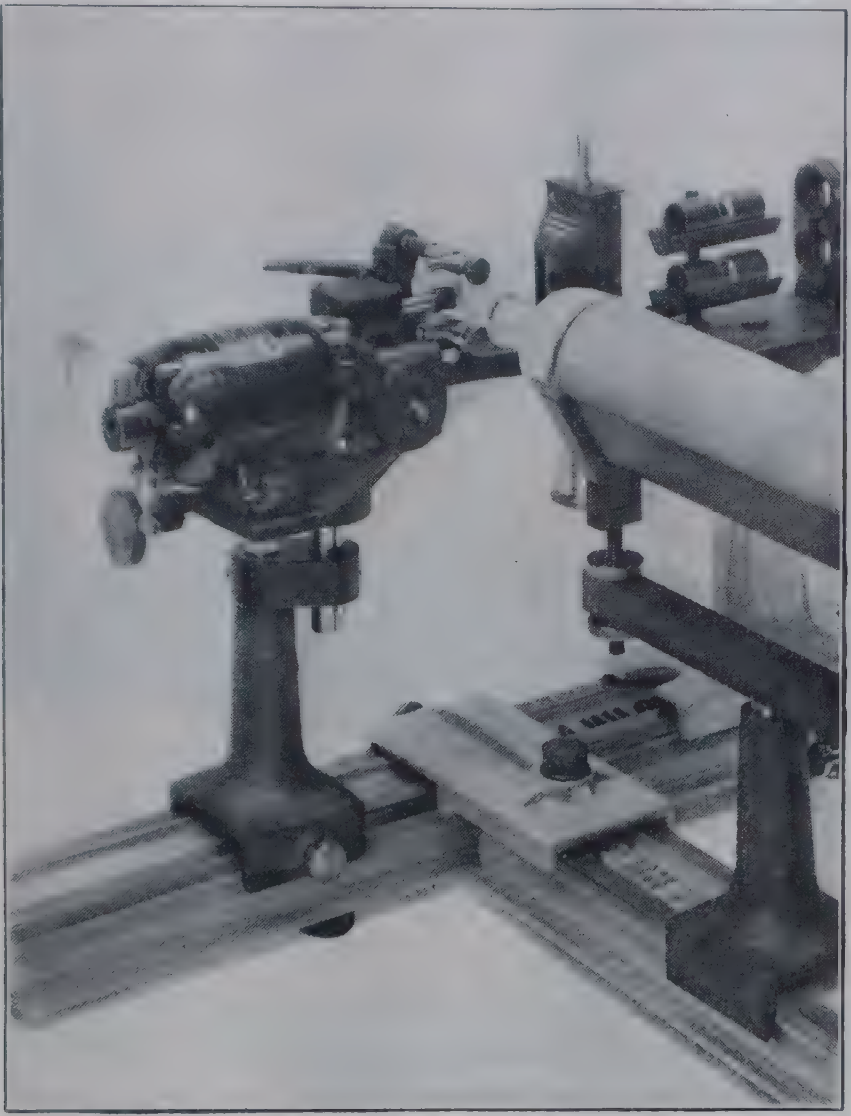


Fig. 7.17. Rocking mirror for concentrated source (Hilger).

to the same objection of synchronism of the reflecting motion with t phase of the current operating the hydrogen tube or other light sour If this speed of mirror motion is set sufficiently slow to avoid the pos bility of this error then one must consider the constancy and uniformi of the light source since only one of the two beams of the photometer illuminated at a time.

The rhomb system for gathering the light from approximately t same angle of view is a distinct advantage in that it makes adjustme of the position of the light source much easier. It is equally possible, course, to construct a sector photometer with a rhomb system of illumi nation to effect this same improvement in ease of adjustment (as in th Bausch and Lomb sector photometer). The Spekker photometer as wel as some of the sector photometer methods (including the Bausch an Lomb instrument) do not permit the reversal of the cells in order t correct for possible instrumental or alignment error.

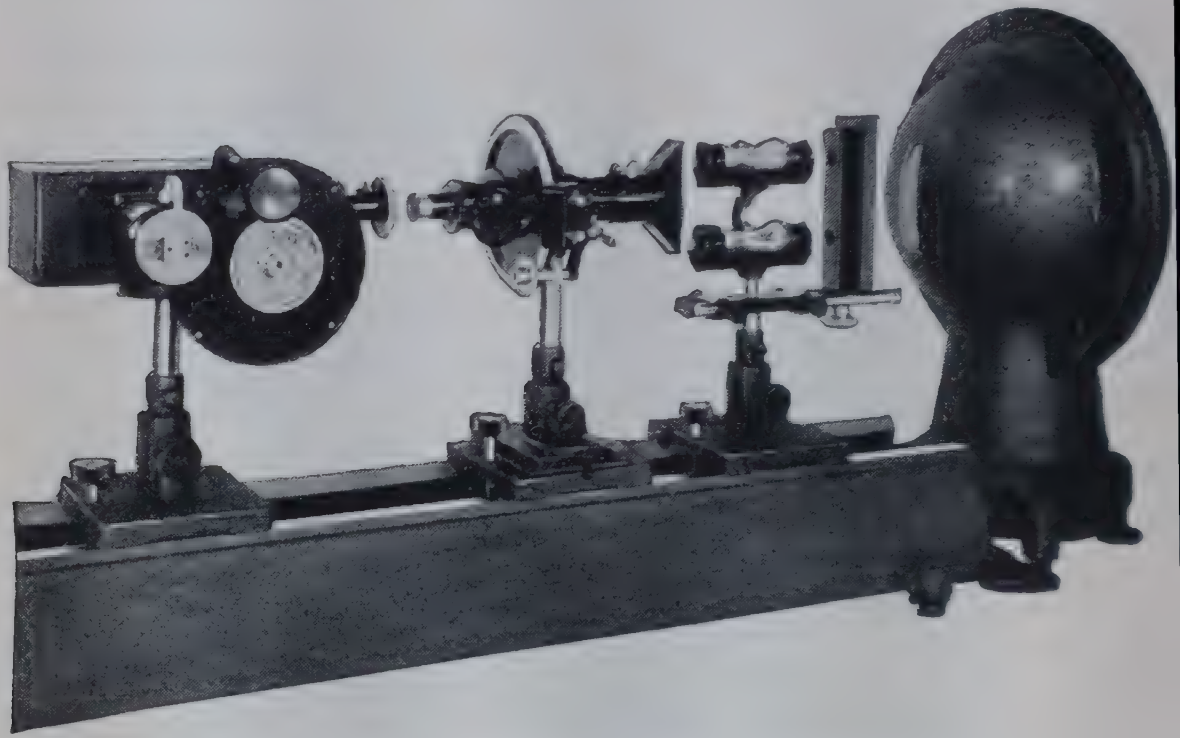


Fig. 7.18. Spectrophotometer (Gaertner).

Instruments involving an optical method (polarized light) are usuall designed for visual measurements, although nearly all of them have photo graphic as well as visual attachments and some of them are of quart construction and designed for ultraviolet operation. In these instrument the beams from the sample and comparison are polarized at right angle to each other by passage separately through two Nicol prisms at righ angles, or at an angle through a common Wollaston prism, so as to pro duce two adjacent beams, which are then passed through the analyzing prism (a Nicol or other polarizing prism) by which the two beams can be brought to the same intensity (Figs. 7.18, 7.19, and 7.20). In some of these spectrophotometers, the polarizing photometer is placed between the dispersing system and the operator or photographic recording means (König-Martens); in others the photometer device is placed between the

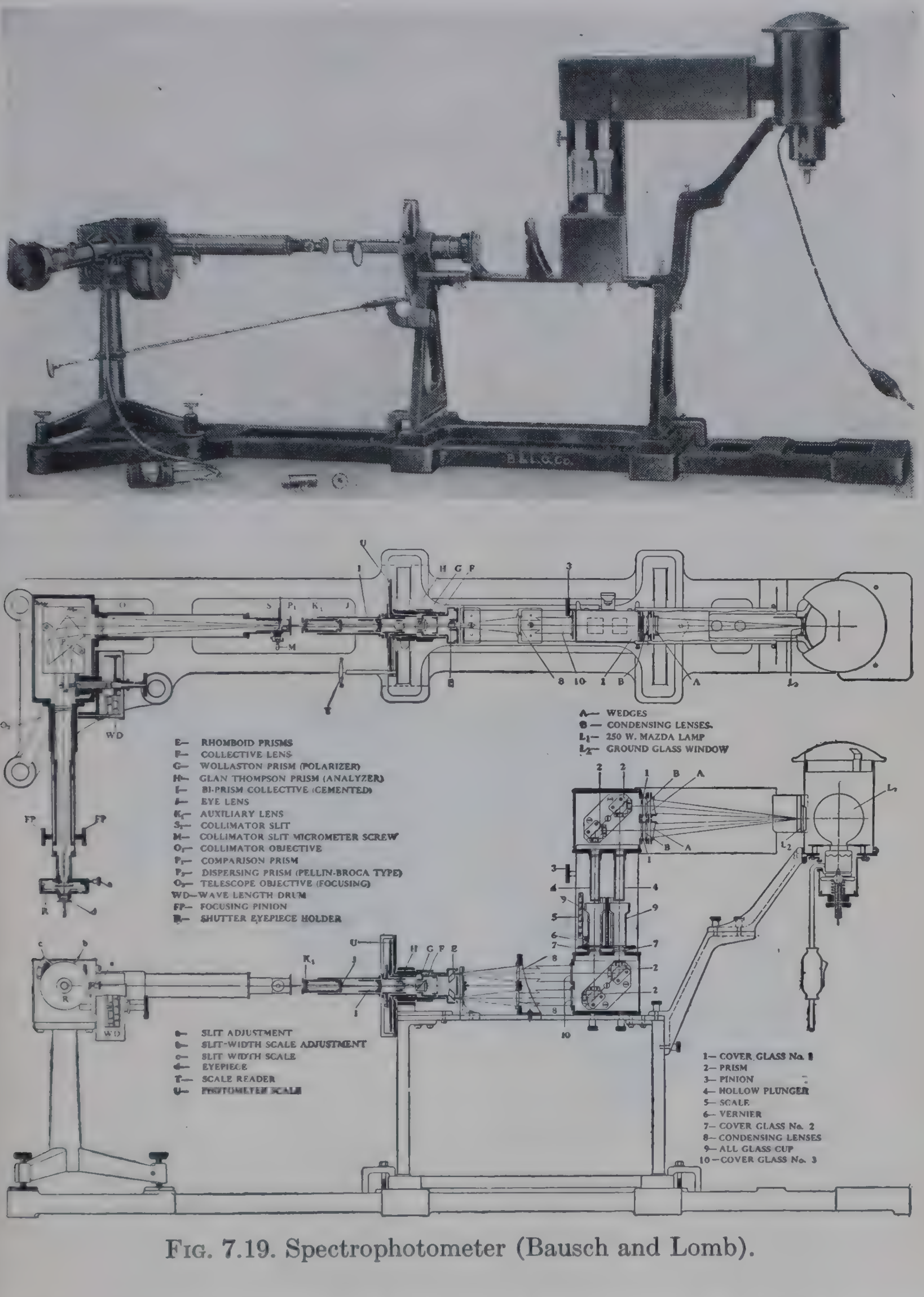


FIG. 7.19. Spectrophotometer (Bausch and Lomb).

light source and the spectrometer slit (Hilger, Bausch and Lomb). I most of these instruments the disk of the analyzer Nicol or other polarizing prism is graduated directly in extinction values, although some ar graduated in percentage transmission or even in angular degrees. Fo purposes of conversion of either of these last two values into extinctio values a special table has been prepared (Table XI, Appendix).

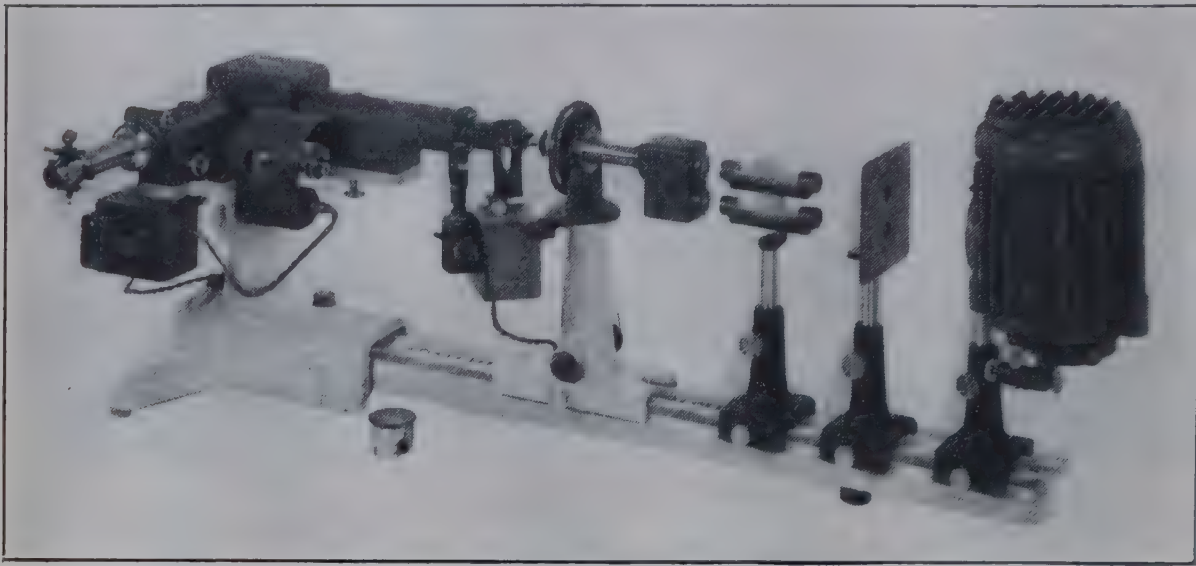


FIG. 7.20. Spectrophotometer (Hilger).

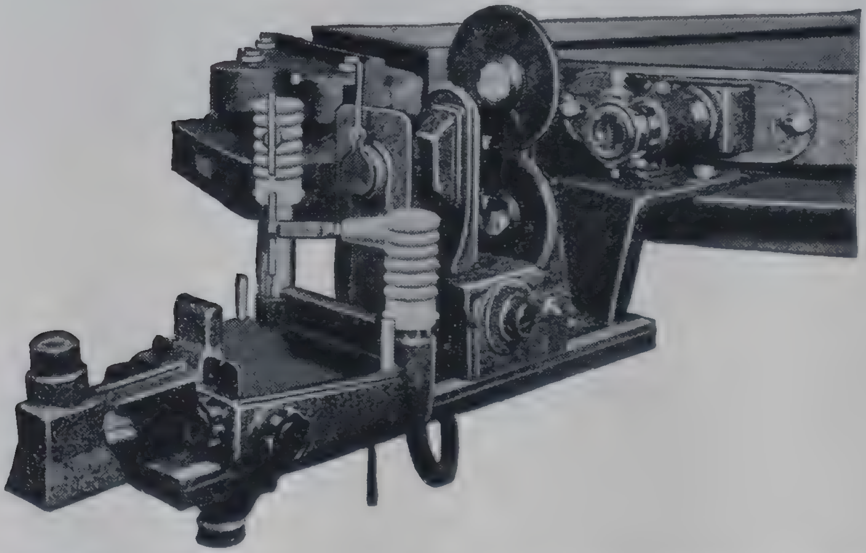


FIG. 7.21. Ultraviolet sector photometer for use on a grating spectrograph (Applied Research Laboratories—Dietert).

PHOTOMETERS APPLIED TO GRATING INSTRUMENTS

By the use of the secondary astigmatic focus of the grating as the position for the biprism or point at which the two beams are brought parallel by other optical devices, photometers similar to those described for prism instruments may be applied to grating instruments. Such a photometer involving two rotating sectors is shown in Fig. 7.21.

PHOTOELECTRIC SPECTROPHOTOMETERS

A number of spectrophotometers have been designed to operate by photocell, thermopile, or photronic cell with which one may measure in rapid succession, using a constant light source, the unknown and comparison samples so as to determine the relative transmission at a given wavelength. Repeating such measurements at a series of wavelengths or frequency values will supply the necessary data to plot an absorption curve. There may be some question as to the relative sensitivity of the photocell or other sensitive device to radiation of differing intensity, so it will be necessary to calibrate the photocell over a range of known inten-

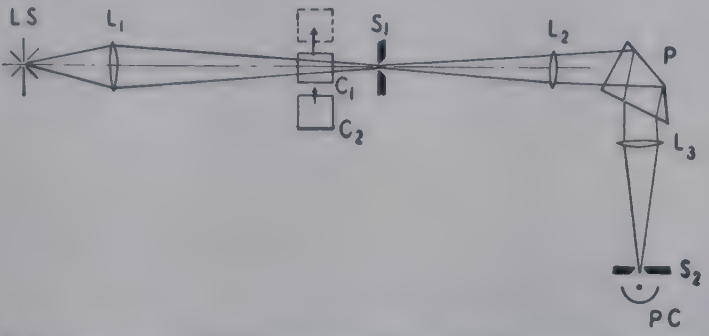


FIG. 7.22. Hogness photoelectric spectrophotometer (*C111*).

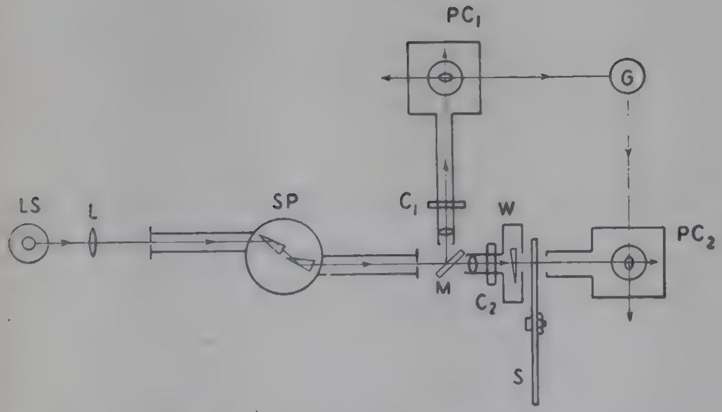


FIG. 7.23. Van Halban photoelectric spectrophotometer; spectrometer (*SP*); half-aluminized mirror (*M*); cells (C_1 and C_2); photometric wedge and sector (*W* and *S*); photocells (PC_1 and PC_2).

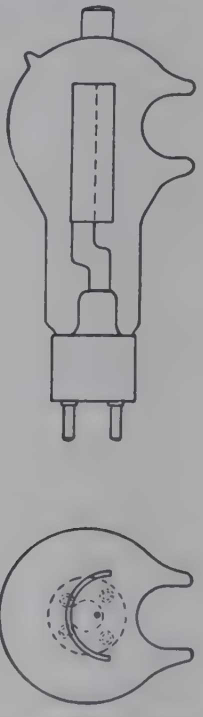


FIG. 7.24. Thin window photocell (Westinghouse).

sity differences or incorporate into the instrument some photomet wedge, screen, or other device to reduce the intensity of the compariso beam to that of the unknown sample (Fig. 7.22). Some photoelectric i struments operate on a null basis, using either two separate cells or means of alternately exposing the same cell to the sample and compariso beams (Fig. 7.23) (*C111*, *C97*, *C90*). The difficulty of obtaining photocel with uniform response over the spectral range makes it more desirable t use a null method involving but one cell, where observations with a accuracy which exceeds the possible cell differences are required. Fo ultraviolet measurement, a quartz photocell or thin window glass ce

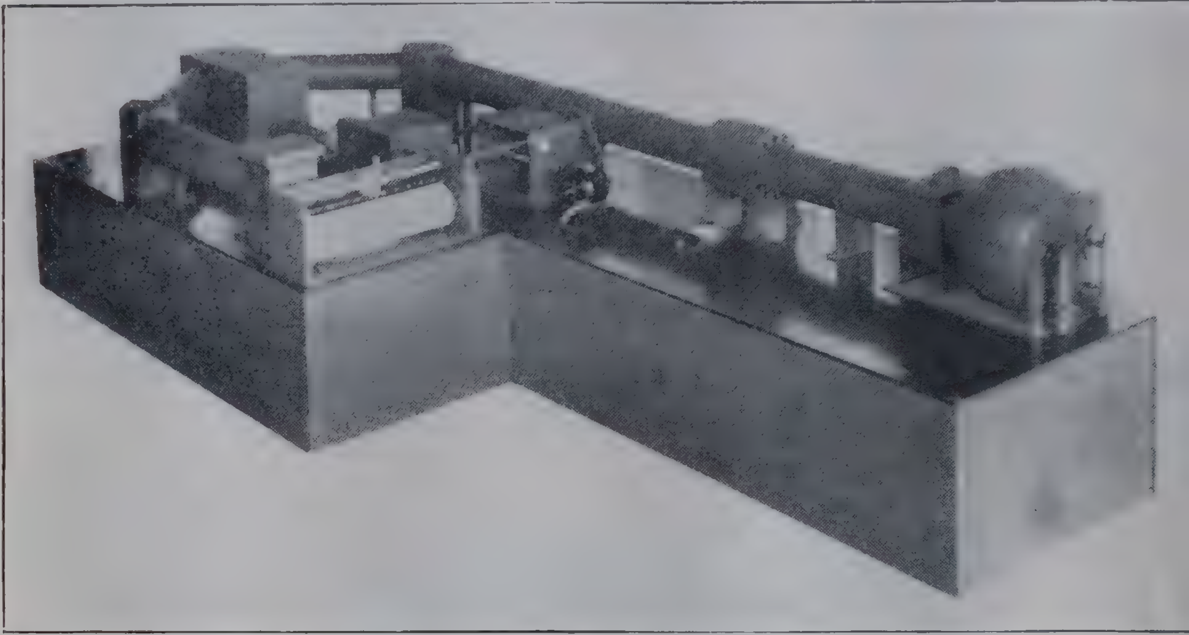


Fig. 7.25*a*. Recording spectrophotometer (Hardy-General Electric [*C97*, *C144*, *C143*]

(Fig. 7.24) may be used; in the visible, photronic cells, photocells, an thermopiles can be used; in the infrared the usual sensitive device i the thermopile, although one may use a photocell to about 1500 mμ

With an electrical value as a measure of the intensity differences i the two beams, it becomes quite a simple matter to connect the electrica circuit to a recording voltmeter such as the Leeds and Northrup Micromax recorder, and to gear or calibrate the motion of the paper to th spectrometer so as to record the absorption spectra in graphical for (*C1*). One of the most successful of these coupled recording devices an one which is commercially available is the Hardy spectrophotomete which is produced by the General Electric Company (*C97*, *C143*, *C144* (Figs. 7.25 and 7.26). This instrument uses two dispersing prisms muc as the van Cittert double monochromator, in which the prisms and tw end slits in the instrument are fixed in position and the dispersion i accomplished by placing a slit at the focal point between the two prisms

In the Hardy spectrophotometer an aluminized mirror serves as one side of the slit and the two prisms are placed so as to have their spectral focal points approximately in the same plane. A single motion of this mirror slit thus changes the spectral region and at the same time corrects for the change in focal length of the lens system used for the different wavelength values.

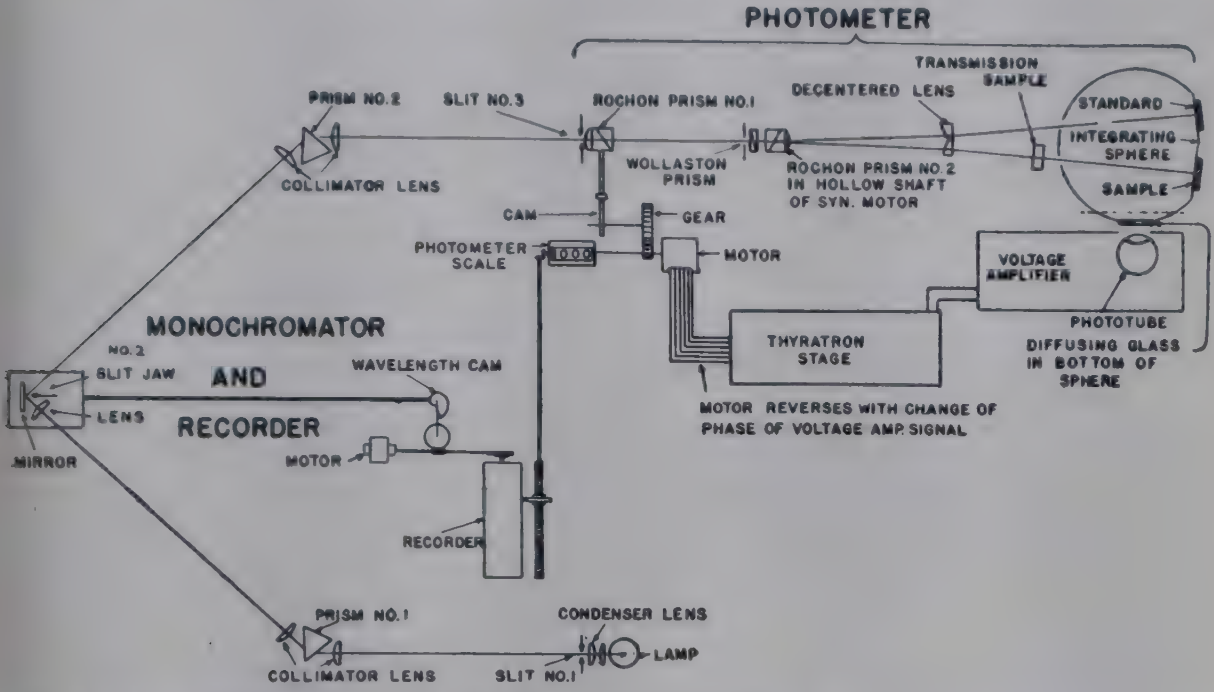


FIG. 7.25*b*. Diagram of recording spectrophotometer (Hardy-General Electric [*C97*, *C143*, *C144*]).

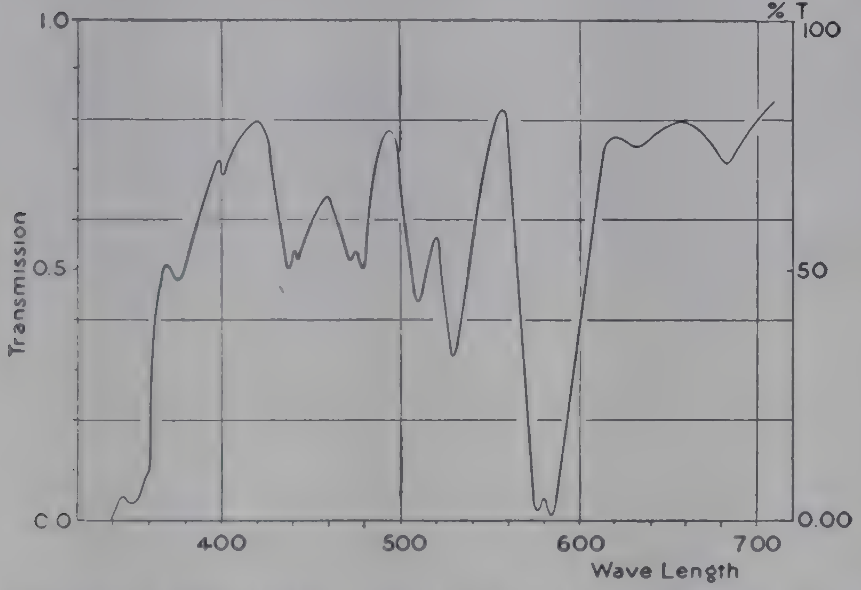


FIG. 7.26. Tracing of transmission record of neodymium glass (Corning G555P) made by the Hardy-General Electric spectrophotometer. (See also Gibson [*C91*].)

In the comparison of the beam intensities one may manually change the cell from one beam to the other (which may be accomplished by interchange of the sample and comparison cell), or, by means of an op cal device, bring into the field of view through the same dispersing syste the light from both sample and comparison beams. The Hardy instr ment utilizes the double polarizing prism system similar to the Köni Martens photometer (Nicol and Wollaston prism) in reverse order, that the light starts from a single beam through the Wollaston pris and is split into two beams, rather than starting as two beams and bei brought together as one beam consisting of two oppositely polariz components. The two components which are obtained in the Hardy i strument are, as in the König-Martens photometer, polarized at righ angles, and a rotation of the Nicol prism enables the operator to matc the two beams to equal intensity. The separation of the two beams pe mits the introduction of the samples to be tested, and after passin through or being reflected from the samples (depending on wheth transmission or reflection measurements are desired) the two beams a again brought together by optical means and are focused on the sam photocell or eyepiece. In the comparison of the two beams electricall one may measure the two beams separately with two photocells, as ha been suggested, by rapid manual alternation, the use of split prisms, o partial transmitting mirrors, or one may focus the two beams on tw halves of a split field photocell (which is made especially for the match ing of two fields). Such photocell amplification would involve d- differences.

A second and very satisfactory method is the alternation of th light beams between the sample and comparison so as to produce an a- response in the photocell if there is a lack of balance in the intensity o the two beams. This alternation effect has been successfully applie through the use of (1) a rotating sector to interrupt the two beam alternately, (2) a vibrating mirror to project the two beams throug the comparison and sample (*C98*, *C99*) alternately, or (3) an additiona polarizing prism if the original optical method involved a polarizin principle so that the two beams are already polarized at right angles t each other. The additional polarizing prism (for which purpose a Rocho prism is quite satisfactory) may be rotated in the beam so as to transmi the comparison and sample beams alternately. A rapid alternating bea permits the amplification of the photocell current through an a-c amplifier which will not respond if both beams are of the same intensity If the beams are not of the same intensity, then the phase of the alternating current will indicate the more intense beam. The control of th adjustable polarizer to bring the two beams to a balance and reduc the a-c impulse can easily be effected by a motor or other device which operates on a two-field principle and depends on whether the two field are in or out of phase as to the direction of motion of the motor armature or phase meter needle. If a motor device is used, as in the General Electric-Hardy instrument, the operation depends upon the phase relation of the field current operating the synchronous motor which rotates the prism, compared with the phase of the amplified armature circuit from the photocell. This motor power also operates a recording pen and produces an automatic record of the absorption spectrum, provided that the dispersion system is coupled to the film or paper to move it along as an ordinate against the abscissa motion of the extinction record.

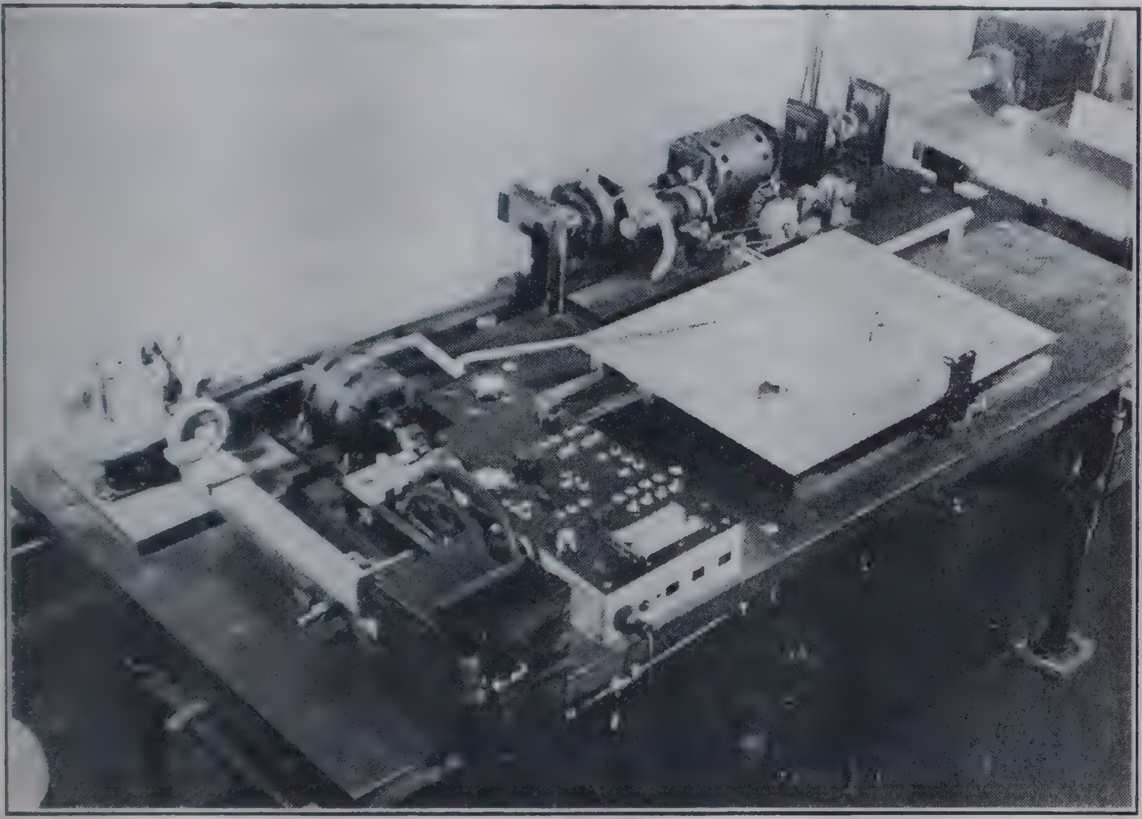


FIG. 7.27. Recording spectrophotometer and spectropolarimeter (Brode and Jones [*C43*].)

The success of this type of machine, especially with regard to high speed and accuracy, has prompted the extension of similar recording means to the ultraviolet region. Two such instruments have been constructed, applying quite different principles of operation and recording. One of these (Brode and Jones [*C43*]) uses as a dispersing system a Wadsworth-mounted quartz prism with a screw motion provided for the lens and slit system in order to keep the monochromatic light source slit in the focal plane of the spectrum and also at the focal point of the collimating lens of the photometer so as to produce a parallel beam in the photometer. The Wadsworth-mounted prism, cut with the quartz

crystal axis parallel to the base of the prism, obviates the necessity f
a Cornu prism since at the angle of minimum deviation of the pris
there is no doubling of the image. Two photometer systems have be
used on this instrument, one involving a rotating mirror sector (al

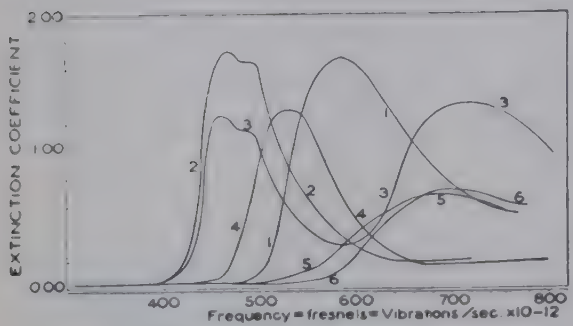


Fig. 7.28. Tracing of extinction record of a series of cellophane filters made by a recording spectrophotometer. (See Fig. 12.32.) (Brode and Jones [*C43*].)

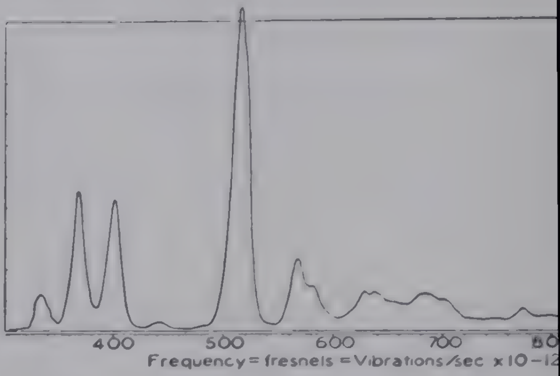


Fig. 7.29. Tracing of extinctio
record of a neodymium glass made o
a recording spectrophotometer (Brod
and Jones [*C43*]).

minized plates) for separation of the beam into two parts alternatel
and a vane photometer principle for reduction of light intensity in th
comparison beam. The two beams are brought to focus on the sam
photocell whose amplified alternating current operated the recordin
pen and changed the transmission vanes so as to produce a match o

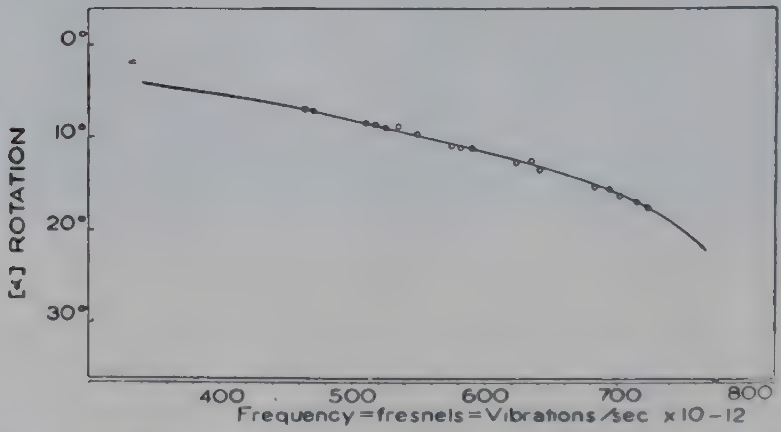


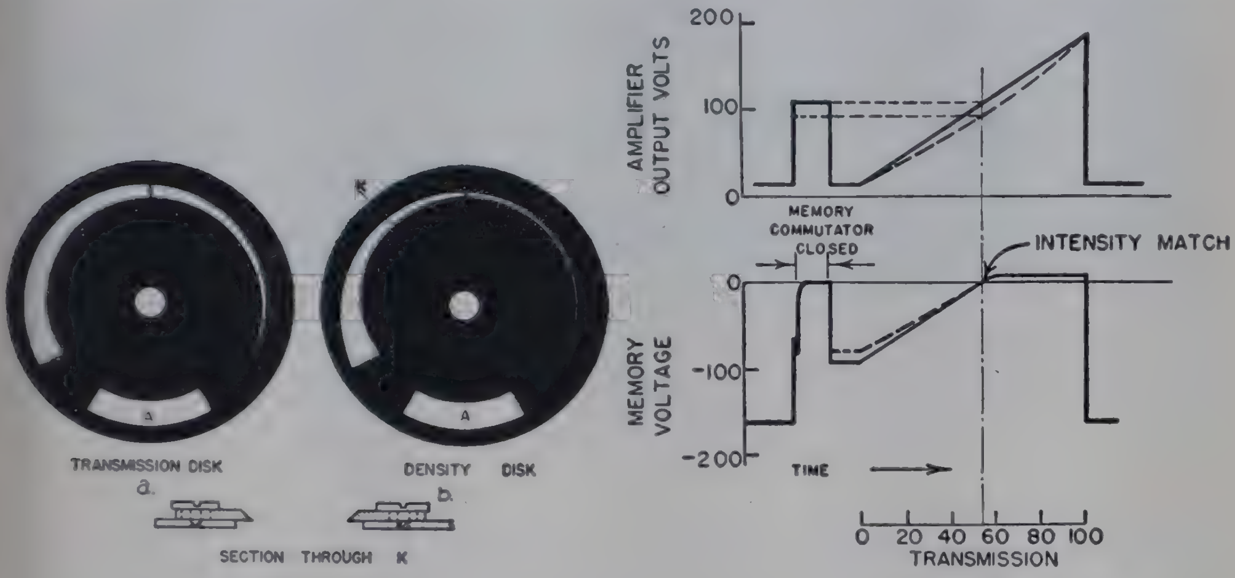
Fig. 7.30. Tracing of a rotatory dispersion curve of sucrose made on a recordin
spectrophotometer-spectropolarimeter (Brode and Jones [*C43*]).

the two beams, the direction of motion of the pen and vane being de
termined by the phase of the amplified current (Figs. 7.27 to 7.30).

Excellent curves have been produced by this method where ampl
light intensity was available, but for lower intensities the higher ampli
fication resulted in out-of-phase currents owing to the cutting edge o
the sector. The photometer was therefore changed to a Jobin and Yvo

instrument which was designed for visual and ultraviolet spectrophotometry. This photometer has special ultraviolet-transmitting polarizer and analyzer prisms, and by suitable arrangement of the parts is available for the determination of optical rotation was well as absorption. The availability of this machine for the graphical determination of optical rotatory dispersion curves in the visual and ultraviolet spectral regions greatly enhances its value to the chemist. The alternation of the two beams on the photocell by a polarizing prism or screen (Hardy method) induces the necessary alternating current for the operation of the matching and recording devices.

The Harrison recording spectrophotometer (*C99*) has a grating rather than a prism dispersing system. A concave grating monochromator with fixed slits provides a spectral band 0.1 to 10 A wide, the purity available depending on the light intensity and the speed of recording desired. An eleven-stage electron multiplier is used to balance a light beam, which has passed through the sample to be measured, against the same beam later reduced to the same intensity by a photometric disk. An electric "memory" device serves to accomplish this balance, and at the instant of balance a spark is passed through a piece of suitable graph paper wrapped around a rotating cylinder, which is mounted on the same axis as a rotating disk which reduces the light intensity at the slit of the monochromator (Fig. 7.31).



(*a*) (*b*)

FIG. 7.31. Interchangeable disks for recording transmission (*a*) and density (*b*) with openings for comparison beam setting (*A*) and observation beam (converging slit). Voltage curves at right indicate condenser charge from photocell circuit resulting from the comparison (*A*) portion of disk and the match point as determined by the rotation of the converging-slit portion of the disk until the photocell circuit builds up a matching charge. (Harrison [*C99*].)

The monochromator light beam is moved from the absorption cell the blank cell once each cycle by the oscillation of a quartz bipris The upper limit on speed of measurement is set by the difficulty oscillating this biprism sinusoidally at speeds greater than those co responding to about 40 measurements per second. Since the balance an entirely electrical procedure it can be carried out with great rapidit

Up to 40 absorption measurements can thus be made and record per second. The instrument will record either transmission or densi values against wavelengths on a linear scale to an accuracy of abo 1 per cent. A density or transmission curve over the range 10,000 3000 A can be traced in 70 seconds, and by changing light sources, t additional range of 2000 A can be covered in a few minutes. When single light source which will cover the entire range 10,000 to 2000 becomes available 80 seconds will suffice for plotting a curve.

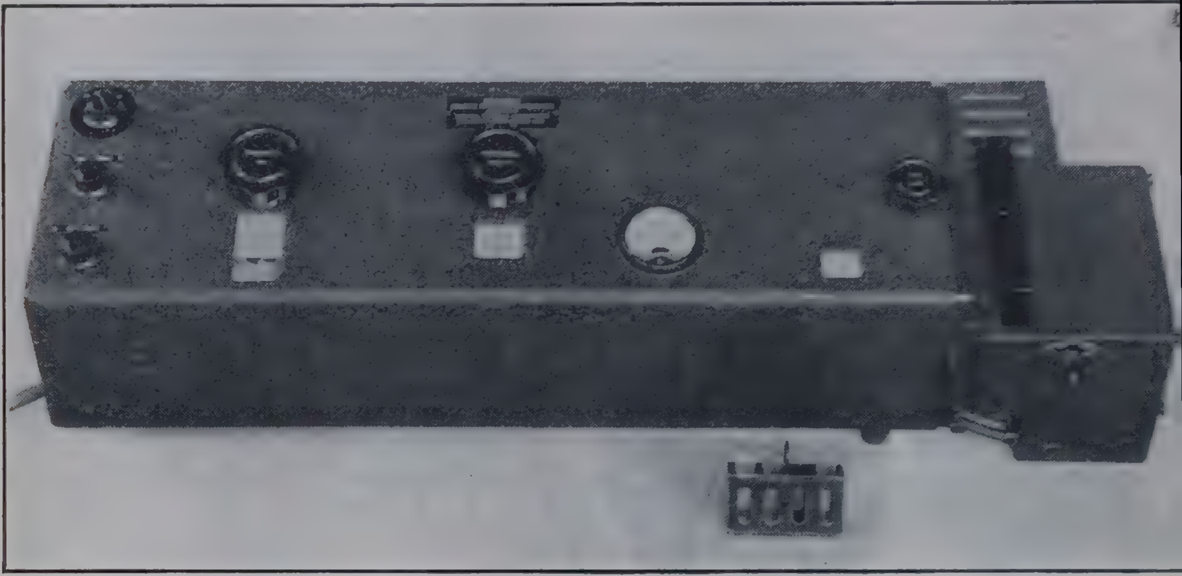


Fig. 7.32. Photoelectric spectrophotometer (Beckman [*C8*]).

The Duplex spectrophotometer produced by the Snow laboratori operates through an alternating beam method with a reproduction the absorption spectrum of sample and comparison in a cathode-ra oscillograph.

The Beckman spectrophotometer (*C8*) involves an optical system wit an incandescent lamp for the violet and near ultraviolet and a ho cathode hydrogen discharge tube for the ultraviolet down to 220 m (Fig. 7.32). The dispersing system is a Littrow-mounted mirror co limated system with a quartz prism. The transmission is measured b phototubes.

The Cenco-Sheard (*C181*) spectrophotelometer covers a range fro

325 to 750 mμ and operates on a monochromator principle similar to that of the Beckman instrument.

The Coleman spectrophotometer utilizes two transmission gratings to obtain a double monochromator effect. Its range is from 350 to 1000 mμ, and, like the Beckman's, its scales are graduated so that one can read directly in transmission and wavelength. The Coleman and the Cenco-Sheard instruments, however, require a separate galvanometer or electrometer for measurement of the photocell current.

Light Sources

The study of the absorption of light involves certain considerations that are not present in emission spectra analysis. The breadth of most of the absorption bands with their rather diffuse edges makes qualitative analysis through the determination of band positions almost impossible except in a few compounds such as the rare earths or hemoglobin. This restriction means that in nearly all applications and measurements of absorption spectra it will be necessary to determine not only the position of the absorption band but also its intensity and shape. With the exception of a few compounds that are photosensitive, there will be no apparent loss of the absorbing substance on extended exposure, and hence an accurate determination of the amount of absorbing substance can be easily accomplished through a measurement of the percentage of light absorbed by the sample. It is obvious that for the determination of absorption spectra the most desirable form of illumination would be one of a heterogeneous nature (continuous spectral radiation) such as is produced from a black-body radiation of dissociation spectra. For observation in the visual spectrum, the near ultraviolet, and the near infrared, the incandescent tungsten bulb is an ideal source of illumination in view

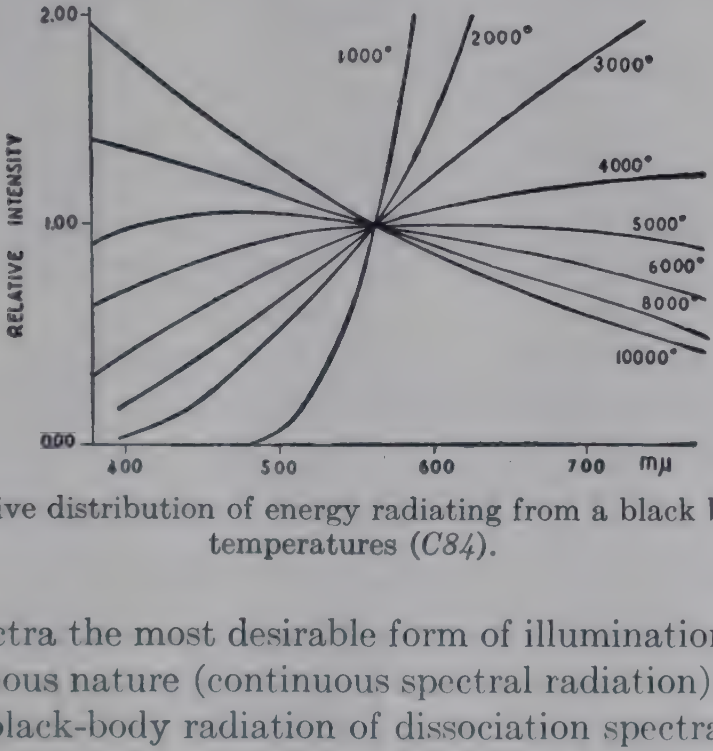


Fig. 7.33. Relative distribution of energy radiating from a black body at indicated temperatures (*C84*).

of its cheapness and the constancy with which it can be controlled. The availability of constant, heterogeneous light sources in absorption spectrophotometry permits the application of other than photographic or integrating methods of observation. It is also possible to increase the light intensity without altering the ratio or percentage absorbed, so that a small slit width can be used on the spectrometer and still sufficient light will be passed through to give an observable effect on a photosensitive device such as a photronic cell, thermopile, or photoelectric cell. Heterogeneous spectrum sources are not an absolute necessity, and in many cases where high light intensity of spectral purity is desired such sources as a mercury lamp will give essentially monochromatic radiation which can be separated by a rather low-dispersion large-aperture spectrometer, or even by filters of colored glass into its monochromatic emission bands. A disadvantage of such lamps is the difficulty encountered in attempting to control them to the same accuracy of radiation intensity as can be applied to the tungsten lamp. (See Fig. 3.40.)

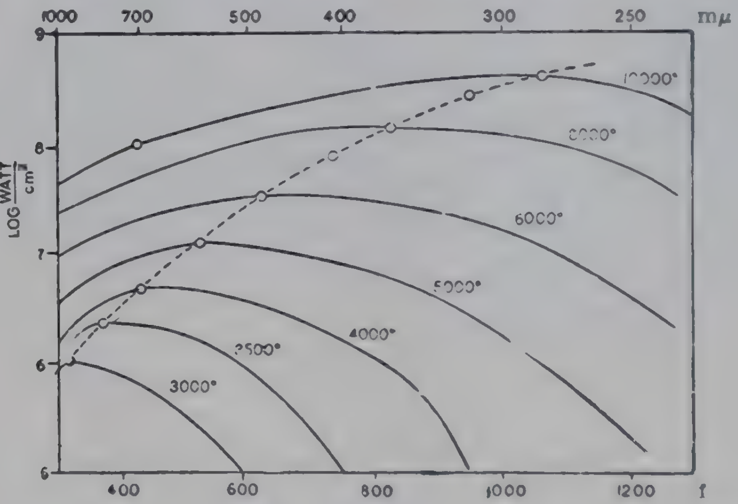


FIG. 7.34. Total energy from a black-body radiator. Note shift of energy maximum towards ultraviolet with increase in temperature (dotted line).

The incandescent tungsten arc (Pointolite lamp) has also been used in spectrophotometric measurements, but is not as satisfactory as condensed-filament or ribbon-filament lamps. For the near ultraviolet it is possible to obtain tungsten-filament lamps with Corex glass envelopes, or, on special order, it is possible to obtain such bulbs with quartz envelopes or windows. Since the temperature of the filament controls the relative amounts of radiation in the various spectral regions, it is quite obvious from these data (*C84*) (Fig. 7.33) that for extreme ultraviolet illumination it will be necessary to burn the lamp at an overvoltage such as is applied to a photoflood bulb. This will shorten the life of the lamp it will increase the ultraviolet radiation by a considerable amount . 7.34).

Within the visible, and for a certain portion of the ultraviolet, the incandescent tungsten-filament lamp provides a very satisfactory lighting source for comparison of beam intensities. For the remainder of the ultraviolet it is desirable to have a similar continuous heterogeneous source. A near approach to such a source can be obtained by sparking between uranium electrodes (an almost continuous background is produced because of the very large number of lines), or by means of a nickel and iron electrode in the arc, which is placed at right angles to the spectrograph slit so as to avoid a difference in line strength in the top and bottom parts of the spectrum.

Various forms of hydrogen discharge provide the best available sources for a continuous heterogeneous source. These may be classified as arcs, discharges, and condensed sparks. A simple arc in pure hydrogen has been found to be satisfactory, although the modification of this type as prepared by Munch seems to offer the most satisfactory continuous source which has so far been made available in the region from 350 to 200 mμ (Fig. 7.35). Hydrogen discharge tubes have been used very extensively (*C187*) (Fig. 7.36) and are ideal where but a single beam of light is to be used and where an a-c effect does not complicate the measurements. Modifications of this type of tube have been constructed with quartz tubing and water cooling so as to permit the utilization of high-density currents with a corresponding increase in the intensity of illumination. A modification of the Munch arc as developed by Allen has a glass or metal casing with sealed-on quartz windows which materially reduce the cost; the metal housing also permits a more efficient cooling and hence a higher current density (*C2*).

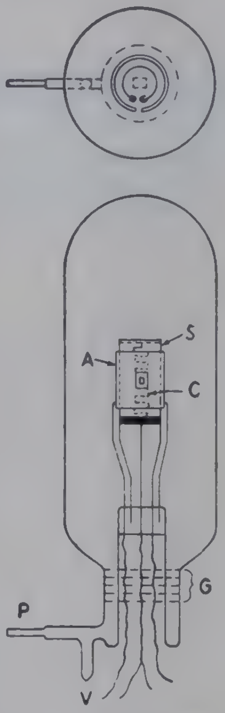


FIG. 7.35. Munch arc quartz bulb; palladium tube (*P*); graded seal (*G*); vacuum seal (*V*); alkaline earth oxide cathode (*C*); nickel shield with tungsten window (*S*); nickel anode (*A*) (*C151*).

The third type of source suggested is the underwater spark (Fig. 7.37). Distilled water has a much higher dielectric constant than air, so that a spark which would normally discharge across a 1-foot gap in air will require a gap less than ¾ inch under distilled water. No metal lines are produced except at the neighborhood of the electrodes, and an excellent continuous spectrum of high intensity is obtained (Fig. 7.37). This linear source, like the filament sources or the Munch arc (in the form of a slit), has a distinct advantage in that the focal length of lenses in the optical system shortens in the ultraviolet, and a linear source permits

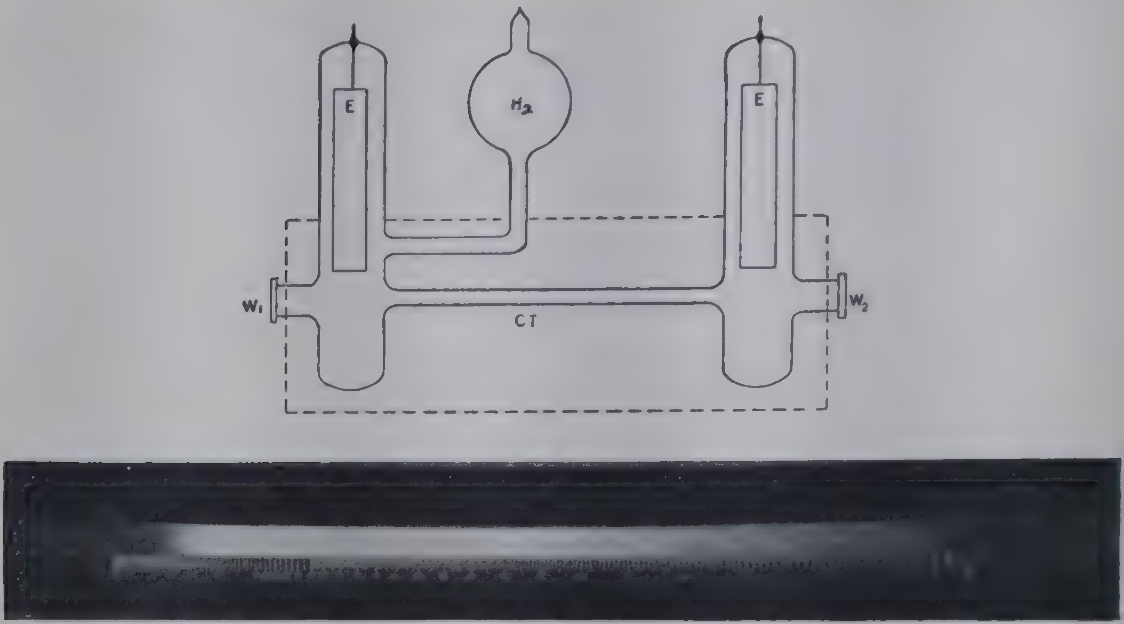


FIG. 7.36. Hydrogen discharge tube for continuous spectra and spectrogram produced.

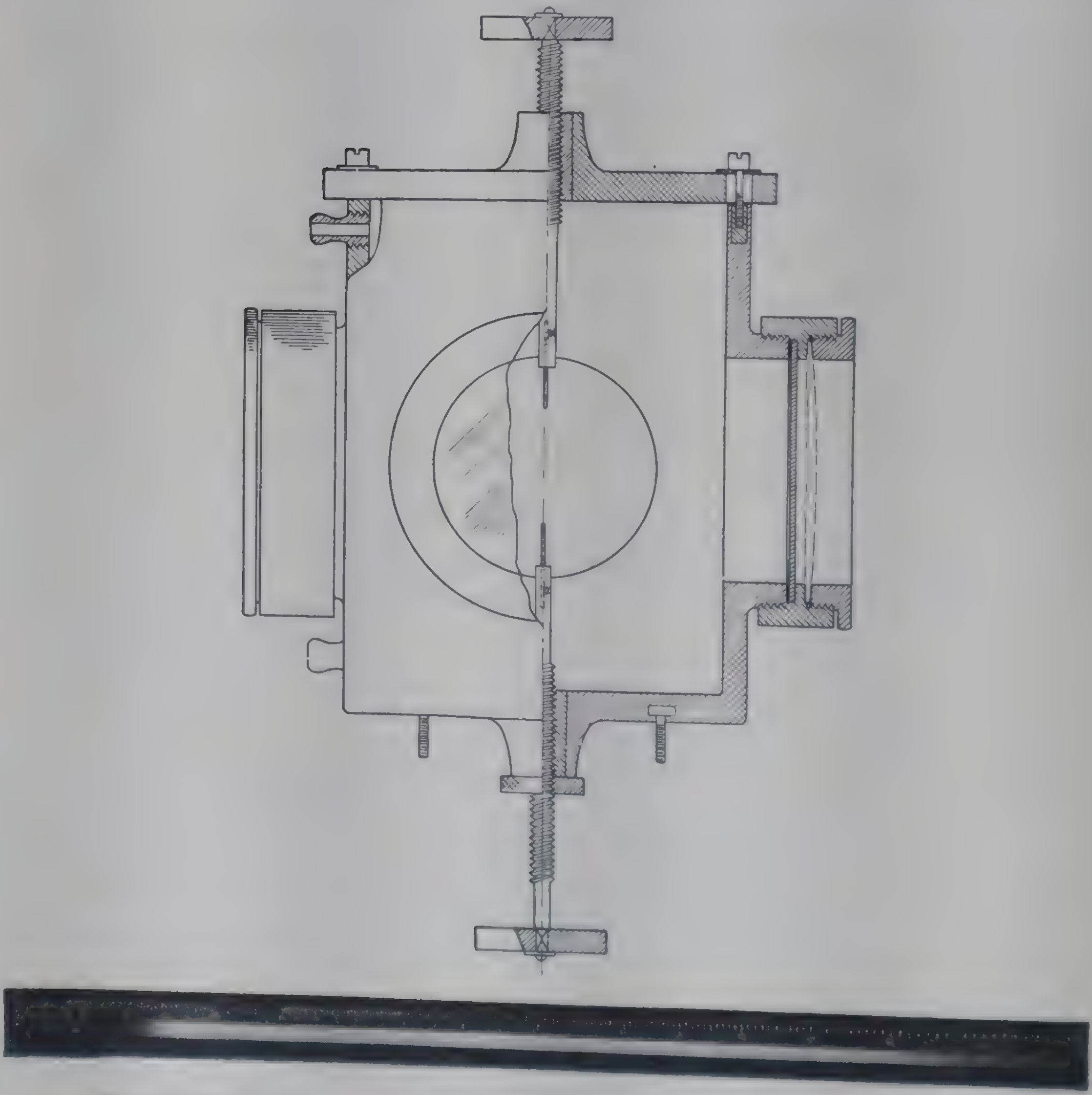


FIG. 7.37. Underwater spark apparatus and spectrogram (*C131*).

considerable shortening of the focus without loss of the image on the spectrograph slit.

The underwater spark requires a Tesla coil circuit and a specially built discharge chamber (*C131*). It is common practice to use tungsten electrodes, although Nichrome electrodes have been found to be equally satisfactory. Aluminum electrodes are not satisfactory since they are deformed by the spark and require continuous adjustment. Tungsten electrodes do not require adjustment more than once every three or four months of fairly steady use, and this adjustment can be quickly and easily made by means of a projection system (placing a light source at the red end of a spectrograph where a plate holder would normally be placed) and casting a shadow of the electrodes on a test screen. The hydrogen discharge and the underwater spark, though quite satisfactory for photographic spectrophotometry, are not suitable for photoelectric photometry where measurements are made by alternating comparison of beam intensities.

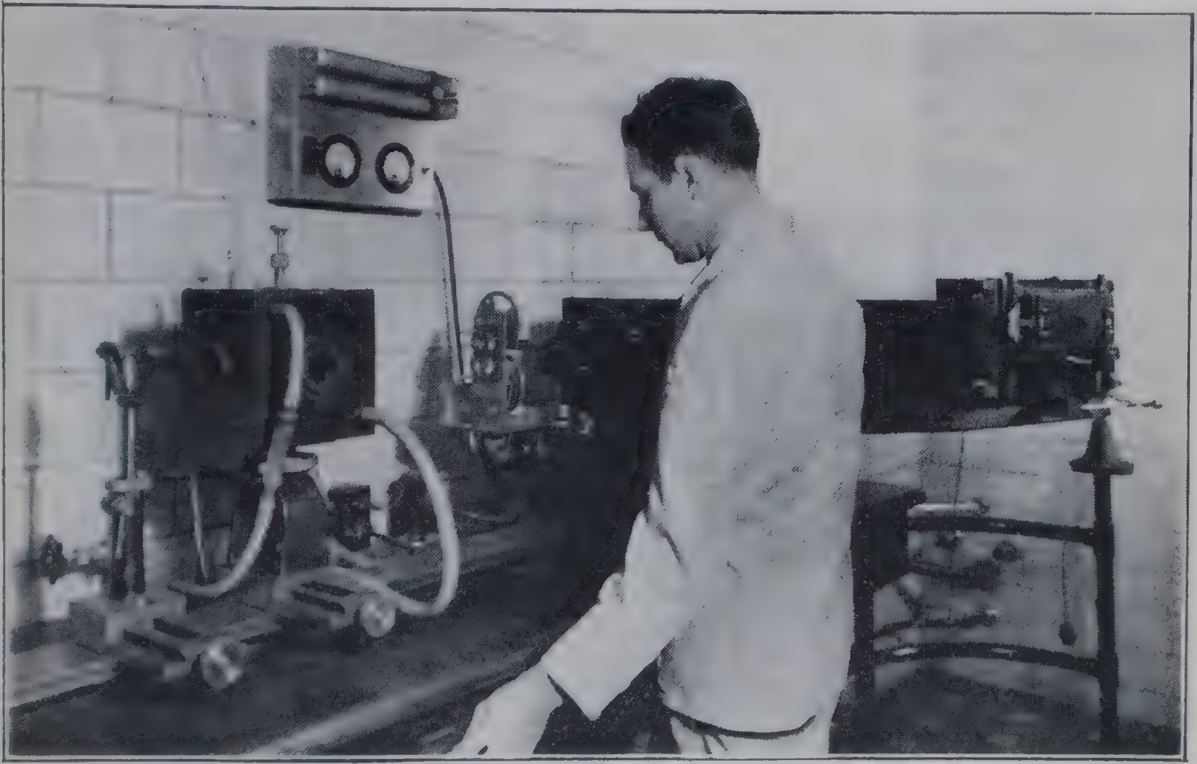


FIG. 7.38. Spectrophotometer outfit with underwater spark, modified Hilger sector photometer and Bausch and Lomb spectrograph. (Resistance and volt-ampere indicator for arc analysis on the wall.) (Note optical bench arrangement.)

As has been suggested previously, tungsten filaments at overvoltage in thin glass, Corex, or quartz bulbs provide a suitable source for a considerable portion of the ultraviolet.

Homogeneous light sources, such as a mercury arc or neon tube, are of some importance in spectrophotometry where wide slits and high light intensity are desired without a sacrifice of spectral purity. The irregular position of the lines and their limited number preclude the general use of such sources, but where only a low-dispersion instrument or only glass filters are available these sources become quite important in spectrophotometric measurements. For visual spectrophotometry sets of filters are available which will give monochromatic light with a mercury, sodium, or other type of vapor lamp. It is thus possible to dispense with a spectrometer and to use these filters directly with a Martens or other type of photometer for an exact determination of the spectral transmission or reflection.

CELLS

A wide variety of cells for holding solutions are available, especially where the observations are to be made in the visible portion of the spectrum and where glass can be used for the cell construction. The development of fused quartz apparatus has extended many of these special cells to forms which can also be used in the ultraviolet. The Baly tube (Fig. 7.5), permitting an adjustable cell thickness, has found extensive application, especially in the earlier work in which the data were recorded as logarithms of the thickness. Accurately ground cylinders and plungers have eliminated the necessity for any gasket or rubber connection at the open end of the cylinder. A similar principle is involved in the Zeiss and Hilger microcells (Fig. 7.39), and in the usual form of colorimeter plunger tube and cell (Fig. 7.41). This latter use requires a right-

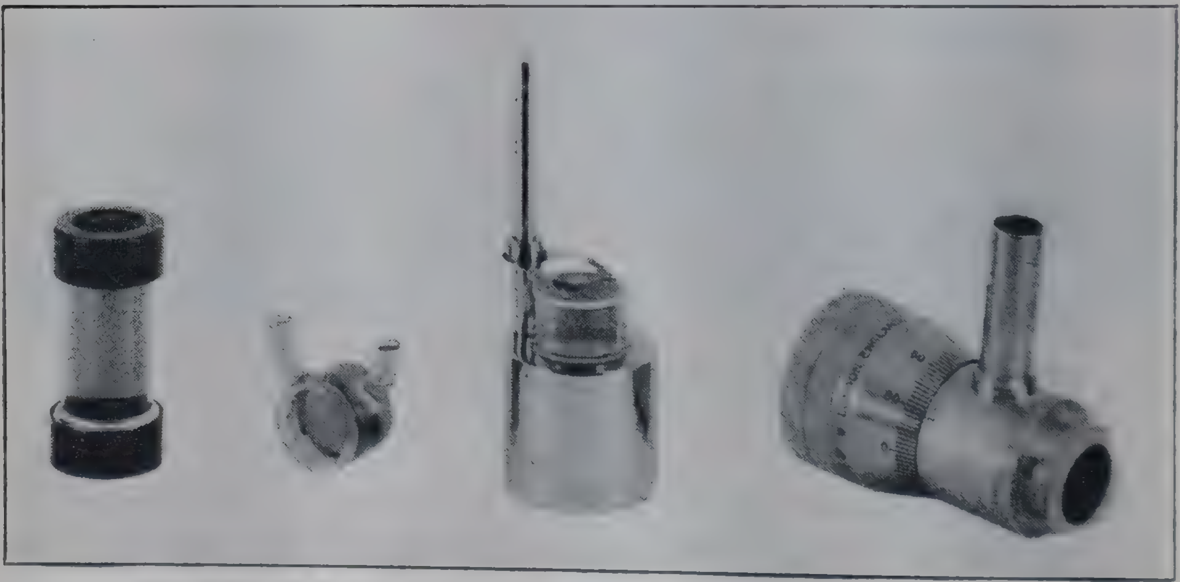


FIG. 7.39. Cells for absorption spectra determinations (Hilger).

ing-prism in the usual optical light path so as to permit the placing of the cell in a vertical position. Such a device is incorporated in the Bausch and Lomb visual spectrophotometer and is of decided advantage where a series of rapid determinations are to be made or where it is desirable to vary the cell thickness for observation in different portions of the spectrum.

Fused-glass, fused-Corex, or fused-quartz cells are available, methods having been perfected for the fusing of flat end plates onto cells without an appreciable alteration of the optical surfaces (Fig. 7.40). Anderson (*C3*) has described cells in which the polished quartz end plates are held by pressure in a permanent holder and are filled by a side tubulation. Such cells have been prepared with a solution thickness of 1 or 2 mm up to 10 cm.

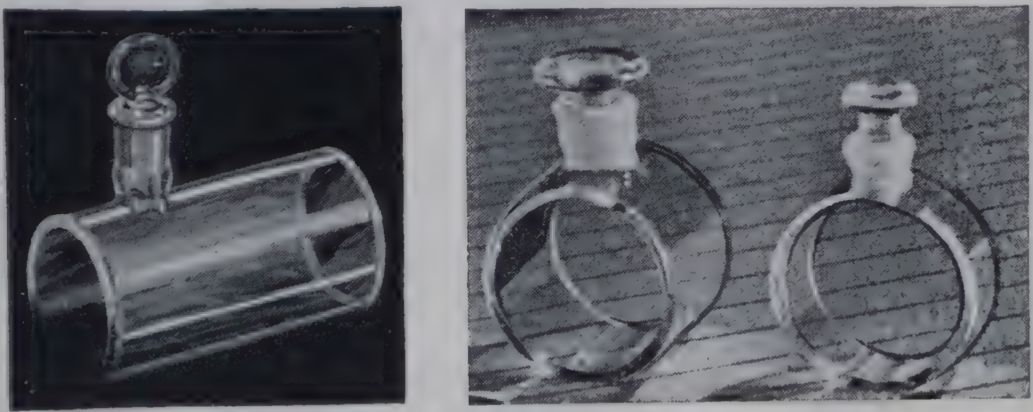


Fig. 7.40. Fused quartz and glass cells for absorption measurement (American Instrument Company and Central Scientific Company).

For some types of observations or certain solvents, cells are available in which the plates have been cemented on with sodium silicate or some other cementing agent, but these are not always satisfactory. Where no change is to be made in the cell thickness during the observation it is desirable to use a cemented or fused cell as described above, or the type consisting of a glass tube with glass or quartz end plates held in position by slight pressure. The last type may involve a glass tube of proper length cemented into a metal tube; or long cells may have metal rings cemented on the ends. These metal tubes or rings are threaded, and a screw cap presses the quartz or glass end plates onto the glass tube end faces. In short cells (and it should be noted that, if the concentration permits, short cells are preferable to long cells in nearly all absorption spectra work) it may be possible to have the glass tube or ring free from and not cemented to the metal tube. It will then be possible to modify the tube by the use of pairs of shorter rings to produce thinner cells than those for which the holder was originally designed. It is necessary, of course, to have available for this purpose cover plates of the same diameter as the glass rings so as to fit in the metal cylinder.

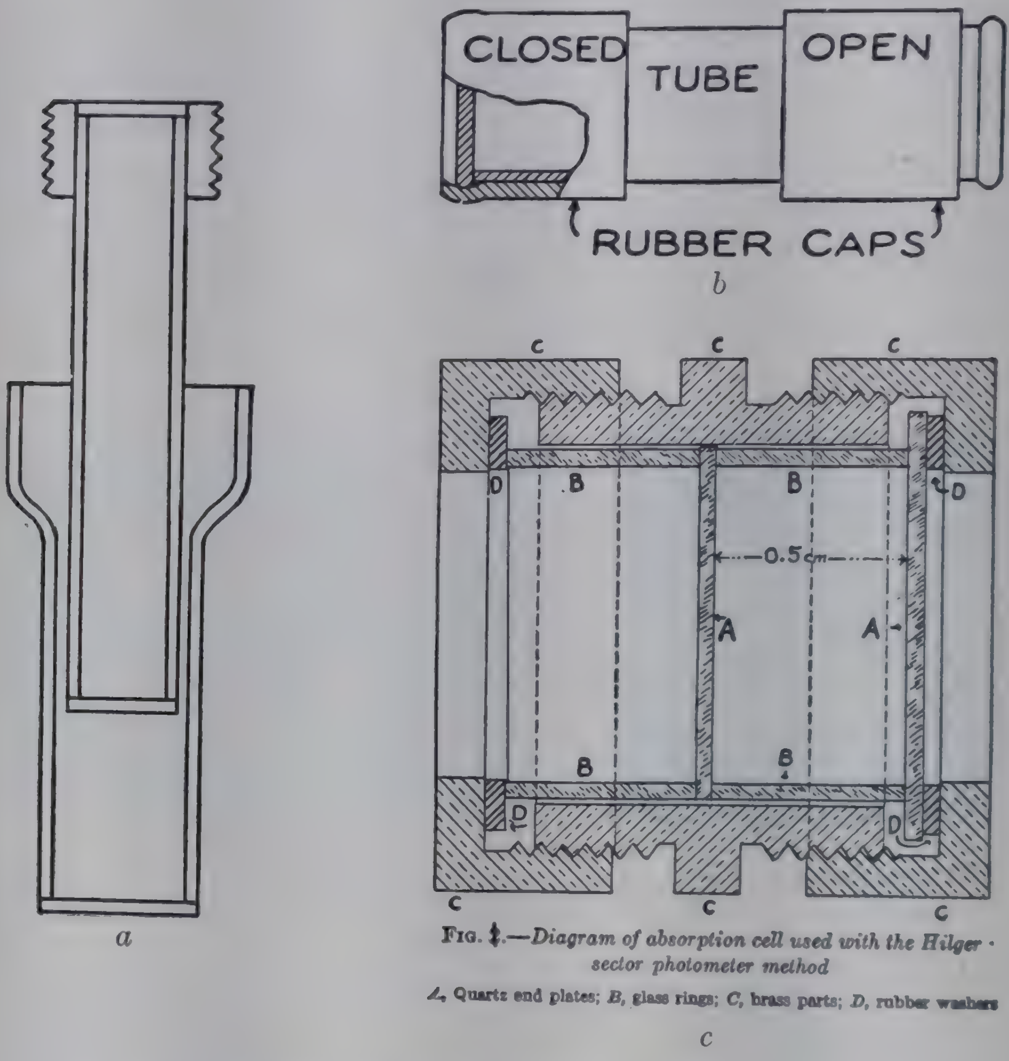


Fig. [illegible].—Diagram of absorption cell used with the Hilger sector photometer method

A, Quartz end plates; *B*, glass rings; *C*, brass parts; *D*, rubber washers

Fig. 7.41. Absorption cells.—*a*. Colorimeter type,
b. Tube type (Brode [*C15*]),
c. Special jacket type (Brode [*C22*]).

One of the most convenient cell types is that devised by Scheibe and others, in which the end plates are held by pressure from each end with no enclosing metal tube (Fig. 7.42). Such holders permit the use of a large number of different cell thicknesses with the same holder. The freedom from metal parts in contact with the cell permits the use of strong acids such as concentrated hydrochloric or sulfuric acid as a solvent. In such cases it is suggested that the cell be modified by placing two rings on each side of it so as to keep metal parts away from it. These cells when properly cleaned and filled will be found to give excellent service and such solvents as diethyl ether will be held without leakage or evaporation for a considerable period of time. Accurately ground rings can be made by grinding down rings of Pyrex tubing of the proper diameter, or complete sets of these cells can be obtained on the market. About the smallest cell thickness obtainable in this type is 1 mm, and such cell rings are, of course, very fragile. For thinner cells rings may

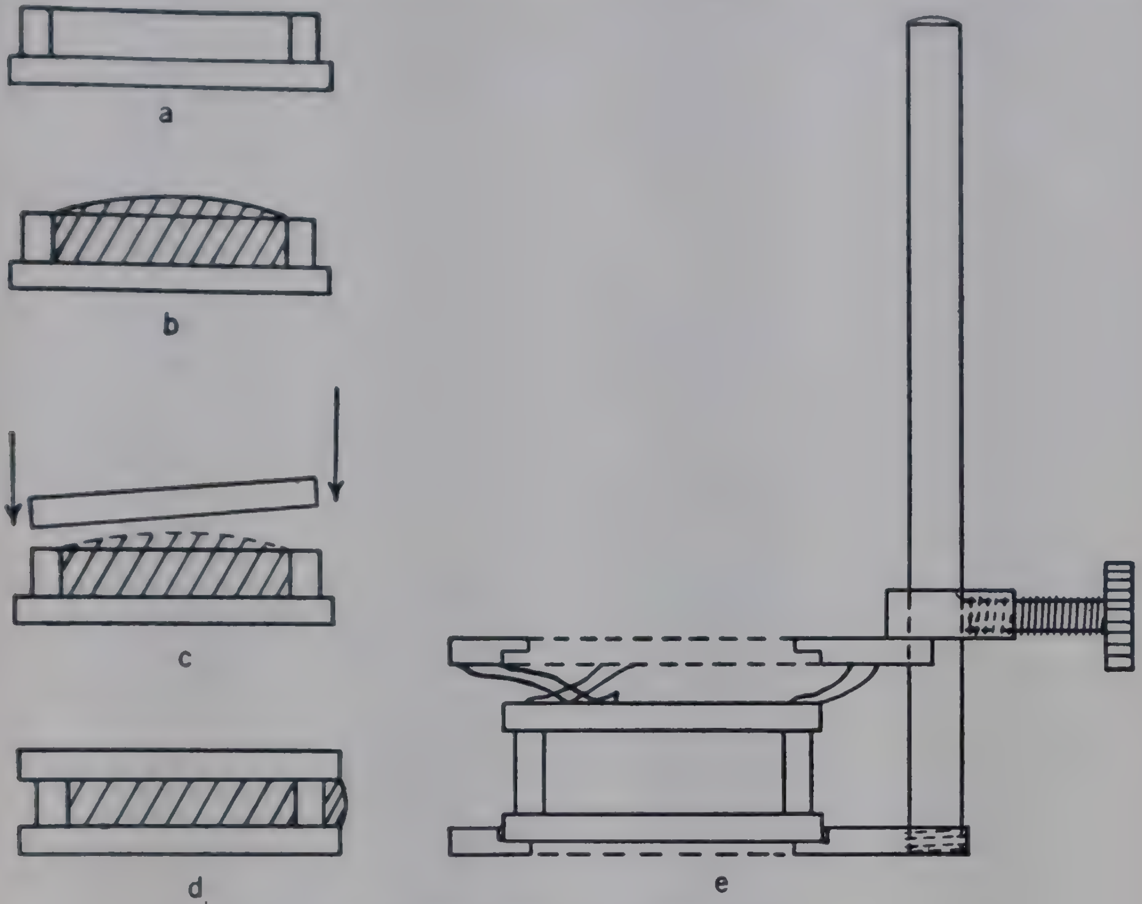


FIG. 7.42. Method of filling cells.

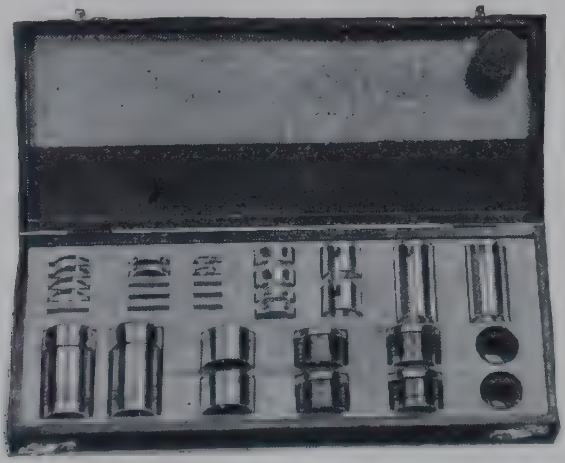


FIG. 7.43. Cells for absorption spectra determinations (Bausch and Lomb).

be made of metal sheet or foil if the sample and solvent do not attack this material (platinum or stainless steel is generally used). For accurate work where thin metal rings are not permissible, cells are available in which an indented area has been ground on a quartz plate so that it amounts to a cover plate and a fused-on ring, the second flat cover plate being all that is required to complete the cell (Fig. 7.43).

SOLVENTS

The concentration of the compound in most solutions which are to be observed spectrophotometrically is relatively low. The absorption, if any, of the solvent will hence act as a rather sharp cut-off to limit the spectral range over which observations may be made. In Fig. 7.45 the cut-off ranges of a number of laboratory solvents are indicated. It should be noted that these are not all chemically pure materials, and the cut-off for such compounds as ligroin would indicate the presence of some impure material, inasmuch as *n*-hexane is transparent to the limit of the photographic gelatin plate. Many of the commercial solvents, especially absolute alcohol, ethyl ether, and ethyl acetate, may have come into contact with benzene in the process of purification, and hence one should be on guard for a series of sharp bands in the region of 1100 to 1300 f. In many observations the presence of a slight amount of absorbing matter will not interfere with the accuracy of the determination so long as a solvent or comparison cell of equal thickness is used in the comparison beam of the photometer.

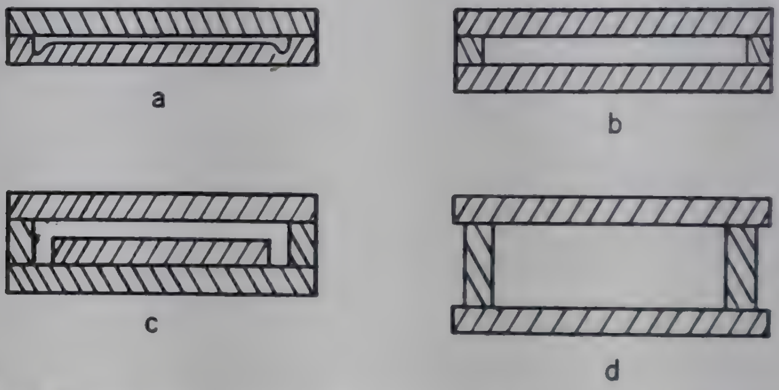


FIG. 7.44. Special cell types for absorption spectra determinations.

The available solvents, in addition to the organic compounds indicated in Fig. 7.45, include many other organic compounds such as the ethanolamines, piperidine, higher alcohols, cyclohexane, or dioxane, as well as many inorganic compounds and solutions, such as water, ammonia, sulfur dioxide, hydrochloric acid, sulfuric acid, and water solutions like sodium hydroxide or ammonium hydroxide. In general, it is possible to classify the solvents into two classes, polar and nonpolar. The nonpolar class includes such inactive compounds as the saturated paraffin hydrocarbons. As might be expected from their nonactive nature, hydrocarbons would not appreciably disturb the vibration of the absorbing molecule, so that the absorption spectrum should more nearly approach its possible spectrum in a vapor state, in which each molecule is separated from the other vibrating molecules by space rather than by inactive molecules (Fig. 7.46).

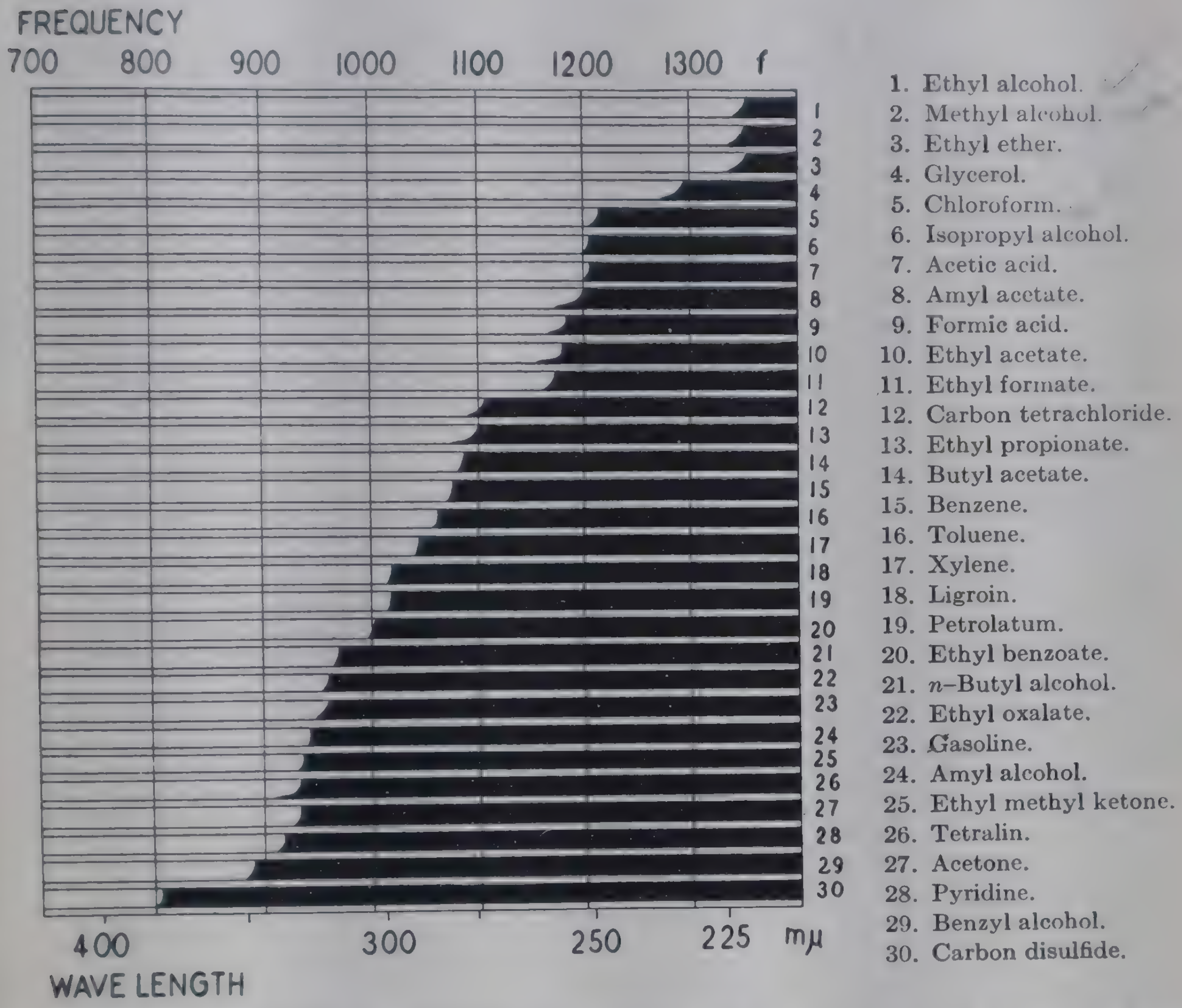


Fig. 7.45. Absorption of commercial solvents for a 1-cm thickness. Slope of edge of band indicates gradual or sharp absorption. It should be noted that these cut-offs were obtained from products of a technical grade and do not represent absorption cut-offs of purified materials (Brode [*C20*].)

As might be expected, polar molecules often take part in an actual chemical combination with the resonating molecule. In such cases, the larger molecule formed may have a charge and property like a polar molecule or ion, and a sharp fine-structure spectrum, such as is usually found in a nonpolar solvent, may be produced. The spectrum of iron or cobalt salts in halogen acids is an example of this effect. In the use of nonpolar solvents with resonating or absorbing molecules which have a tendency to form complexes with polar solvents, one should be very careful that the solvents are free from any of these polar solvents. Iodine, in a nonpolar solvent such as $CHCl_3$, produces a sharp band at 578 f, but in alcohol, water, and potassium iodide, or other polar solvents it produces a brown rather than purple solution with bands at 850 and 1040 f (Fig. 7.47). It is only necessary to add a drop or two of alcohol to a purple

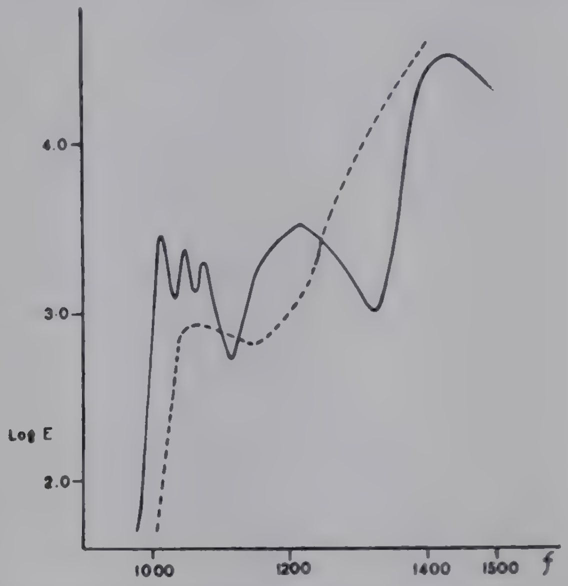


FIG. 7.46. Absorption spectra of phthalic acid in hexane (dotted) and alcohol (solid) (Menczel [*C141*]).

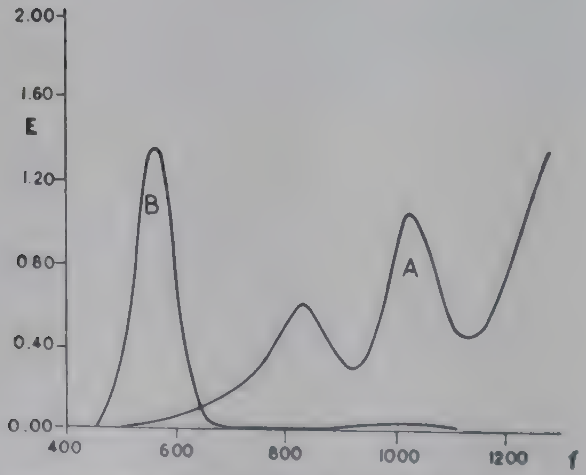


FIG. 7.47. Absorption spectra of iodine in alcohol (*A*) and carbon tetrachloride (*B*) (Brode [*C19*]).

$CHCl_3$-iodine solution to change it from a purple to a brown color, showing that the resonating molecule is apparently dissolved in the polar solvent (alcohol), and that this complex or solution is in turn dissolved in the nonpolar solvent. A similar example of this solvent effect is shown in the absorption spectra of phenylazophenol in mixtures of alcohol and benzene and in mixtures of alcohol and CCl_4 (Fig. 7.48 and 7.49). These latter experiments also show that Kundt's law (absorption band of a compound is shifted in accordance with the refractive index of the solvent) does not hold. Less than 1 per cent of alcohol is sufficient to shift the postion of the absorption band from 875–880 to 855 f. In view of this rather marked shift, and the known alteration in the band appearance itself with pure nonpolar solvents, it would seem advisable to

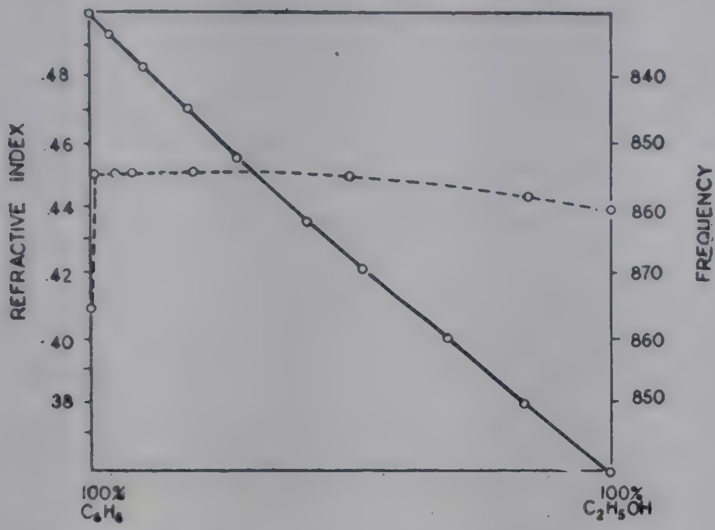


FIG. 7.48. Effect of mixtures of alcohol and benzene on the refractive index and absorption frequency of phenylazophenol. (Dotted line = frequency.) (Brode [*C20*].)

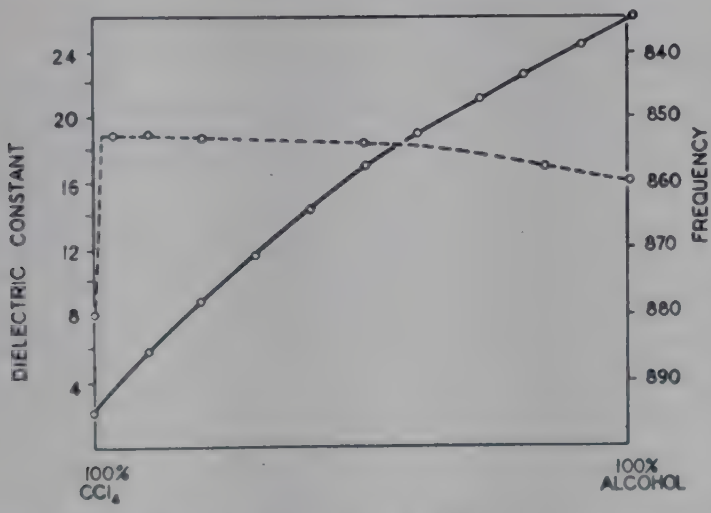


FIG. 7.49. Effect of mixtures of alcohol and CCl_4 on the dielectric constant and absorption frequency of phenylazophenol. (Dotted line = frequency.) (Brode [*C20*].)

be quite sure of the purity of the solvent or else to add sufficient alcohol or other polar solvent to obtain uniform and consistent results.

The effect of temperature on the absorption spectrum of a solution will be indicated in the restriction of molecular vibration as the temperature is lowered, so that at temperatures of liquid air or lower many colored compounds will become colorless. At room temperatures and higher the effects are largely those shown by polar solvents in which a reaction takes place between the chromophore and the solvent. Such effects as the change in intensity of iodine in alcohol and the pink to blue color change of aqueous or basic cobalt solutions are of this type. Another effect which is of importance, although little has been done in the field, is that of thermochromic compounds which are colorless at low temperatures and colored at high temperatures in what appears to be a reversible reaction, the chromophoric structure being induced by the higher temperature. An example of this type of compound is found in 1–(α–dimethylaminobenzyl)–2–naphthol (*C44*).

TEMPERATURE

It is obvious from the discussion on band spectra that the lowering of the temperature will decrease the potential energy and result in a concentration of absorption in the lower states. The concentration or limitation of absorption to a certain frequency range will result in a resolution of the absorption band into sharper and more defined components (see Fig. 7.50) (*C123*).

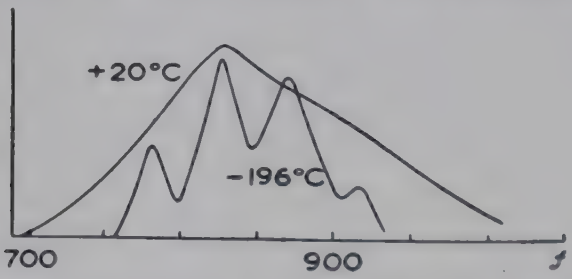


FIG. 7.50. Influence of temperature on the resolution of component structure in absorption bands. Absorption spectrum of dodecapentanoic acid in ether-alcohol (Lewis and Calvin [*C123*]).

ABSORPTION SPECTRA (THEORY OF MEASUREMENT AND RECORDING) (*A23*, *B21*, *B29*, *B57*, *B69*)

The transmission (T) of a substance is a measure of the light intensity transmitted (I) by the material as compared to the intensity of the incident beam (I_0).

$$T = \frac{I}{I_0} \tag{1}$$

The transmission factor (T) cannot be greater than unity. The percentage transmitted (transmittancy) (t) is obtained by multiplying the transmission factor by 100. In accordance with Beer's and Lambert's laws, the following relationship between I and I_0 is found to hold:

$$I = I_0 \cdot 10^{-kcd} \tag{2}$$

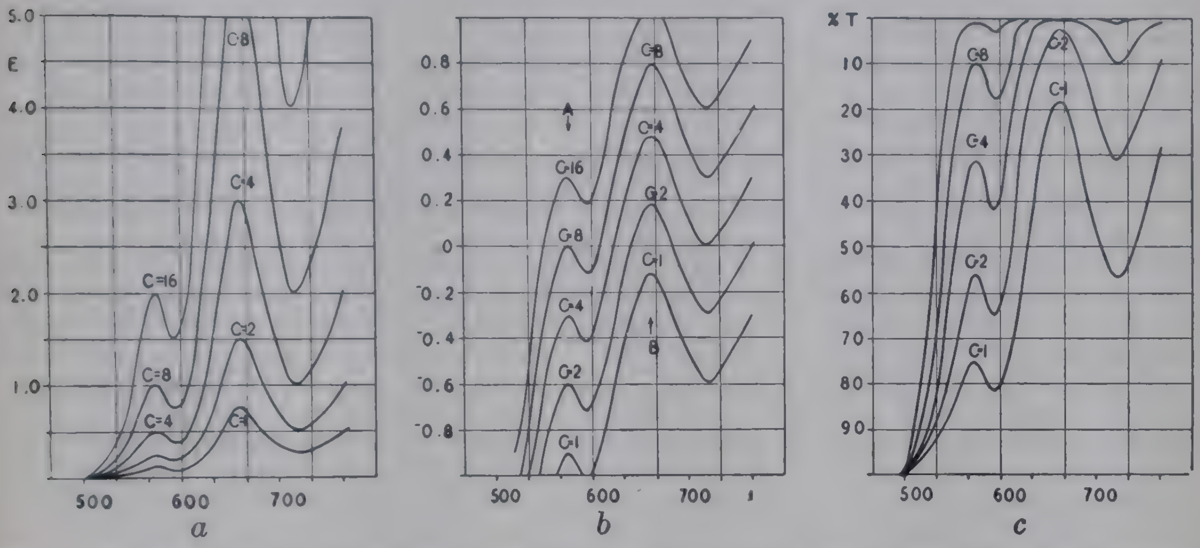


FIG. 7.51. Graphical indication of absorption spectra. (See Table XI for interconversion of these systems page 615.)

a. Extinction (E) = $\log I_o/I$.

b. Log E.

c. % transmitted = $100 \times I/I_o$.

Note how percentage transmitted curves flatten the peaks and reduce the significance of high absorption as compared with low absorption values.

where k is a constant for the wavelength and compound under observation, c the concentration, and d the thickness of the cell. For solids of unknown concentration the c will drop out and the expression becomes

$$I = I_0 \cdot 10^{-kd}$$

In this form the equation is essentially the Bunsen and Roscoe relation in which k is defined as the extinction coefficient in accordance with the following relations: Let I_0 be the intensity of the incident light which enters the medium; I the intensity after its subsequent passage through the path length (d); and k, a constant depending on the medium and wavelength (Fig. 7.51*a*). The Bunsen and Roscoe extinction coefficient is the reciprocal of the thickness which is necessary to weaken the light to one tenth of its incident value (*C57*).

Lambert's law may be expressed thus: the proportion of light absorbed by a substance is independent of intensity of the incident light but varies directly as the logarithm of the thickness. For all substances which have been examined this law has been found to hold. Beer's law states that the proportion of light absorbed is directly proportional to the number of molecules of absorbing substance through which the light passes.

Since k, c, and d are the determining factors in recording data, and, in general, an attempt is made to match or equate light intensities, the expression of Bunsen and Roscoe is more useful in the form

$$kcd = -\log_{10}\frac{I}{I_0}$$

It is quite acceptable to write $-\log I/I_0$ as $+\log I_0/I$ although publications from the Bureau of Standards (*B21*) record kcd as a negative value and plot downwards on an ordinate basis. Curves from the Bureau of Standards are known as "spectral transmission" or "spectral absorption" rather than absorption spectra curves and have "peaks" or maxima at the bottom and minima at the top of the graph. There is a uniform agreement among practically all other workers (*B29*, *B76*, *B78*) to plot absorption spectra curves with the extinction arranged as a positive value along the ordinate of the graph form (Fig. 7.51*b*).

Since k in the Bunsen equation is a fixed constant independent of the concentration and thickness (c and d), and the observed value is the expression $\log I_0/I$, or its equivalent which is kcd, it is obvious that this expression is in itself a useful form, and hence we may indicate

$$E = kcd$$

where E is defined as the extinction coefficient or extinction, and k as the specific extinction, i.e., the extinction for a unit concentration and unit thickness. The same differentiation exists here between the extinction values as between other physical properties such as optical rotation or density. In optical rotation we use an expression α to indicate rotation, another expression $[\alpha]$ to indicate specific rotation (i.e., rotation per unit concentration and unit cell thickness), and, lastly, an expression [M] to indicate rotation per unit molecular concentration and thickness. The same may be said with regard to weight, specific weight, and molecular weight. It would therefore seem quite logical to use some expression to indicate molecular extinction, e.g., ϵ, which is equivalent to the specific extinction, k, multiplied by the molecular weight.

On account of the great differences in the extinction values of certain compounds, it is often more convenient to plot as ordinate values $\log k$, $\log E$, or $\log \epsilon$, or as k, E, or ϵ times a power of 10, i.e., $E \times 10^3$, so as to permit a better comparison between compounds with weak and strong absorption values. It will be noticed that the recording of log E values for the same curve at different concentrations will produce a curve of the same shape but of different ordinate values (Fig. 7.51*b*).

Beer's law has been shown to apply to most solutions, except where some chemical reaction takes place, such as association, ionization, or dissociation, which will change the nature of the chromophore or the number of molecules in solution. In general it can be assumed to apply, and must be so assumed to apply, when quantitative analyses are made by means of extinction values in solutions of unknown concentration, unless a known series of standards has previously been prepared and the amount of increase or decrease in the absorption caused by solution action has been determined for various concentrations.

In 1883 Hartley published a series of observations on the absorption spectra of determinations on an instrument used by Miller in 1860, on which the first serious investigations on absorption spectra had been made (*C102*). In his experiments, Hartley recorded the thickness of the solution at which light ceased to be transmitted by the solution. By increasing or decreasing the thickness of the absorbing cell he could record a quantitative indication of the absorption band shape (Fig. 7.52). The logarithm of thickness rather than the thickness itself (Fig. 7.3) was soon shown to give a much better indication of the absorption. Similar observations also were made keeping the cell thickness constant and gradually diluting the solution so that the absorption curve was obtained by plotting the wavelength values against the concentration or logarithm of concentration (Fig. 7.53). In many of these earlier data the curves were produced by straight lines with sharp angles, and, though they give a qualitative representation of the absorption, they do not supply sufficient accuracy to satisfy the exacting requirements of the analytical methods of today. The curves for *p*-phenylazophenol (Fig. 7.54) as obtained by three earlier workers can be compared with the same curve as obtained by the Hilger sector photometer method (*C20*)

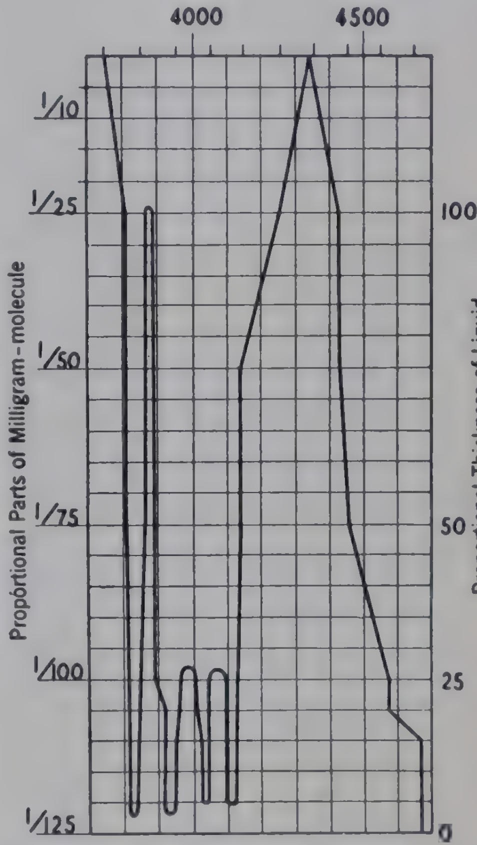


Fig. 7.52. Absorption spectrum of benzene (after Hartley [*C101*]).

(Fig. 7.55), in which the accuracy of observation is considerably better than the size of the circles which indicate the points.

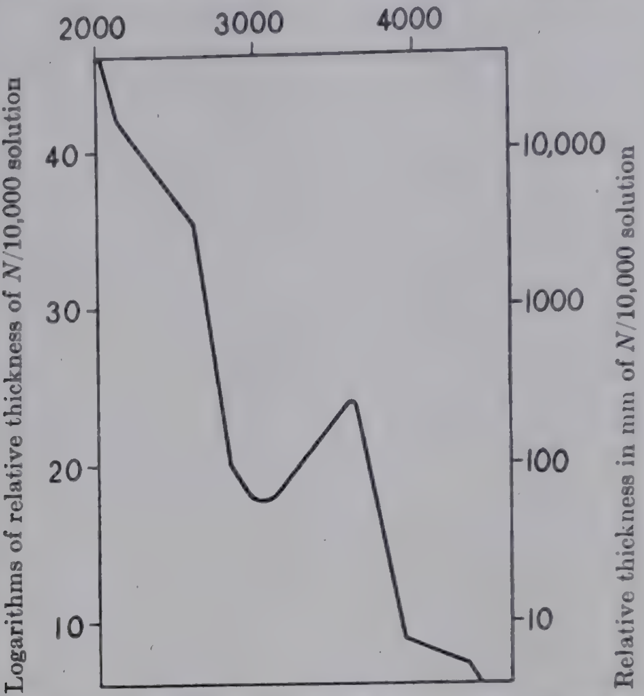


Fig. 7.53. Absorption spectrum of α-naphthaquinone (Baly and Stewart [*B77*]).

It is unfortunate that so much effort was put into quantitative measurements on the log thickness or concentration methods since equal

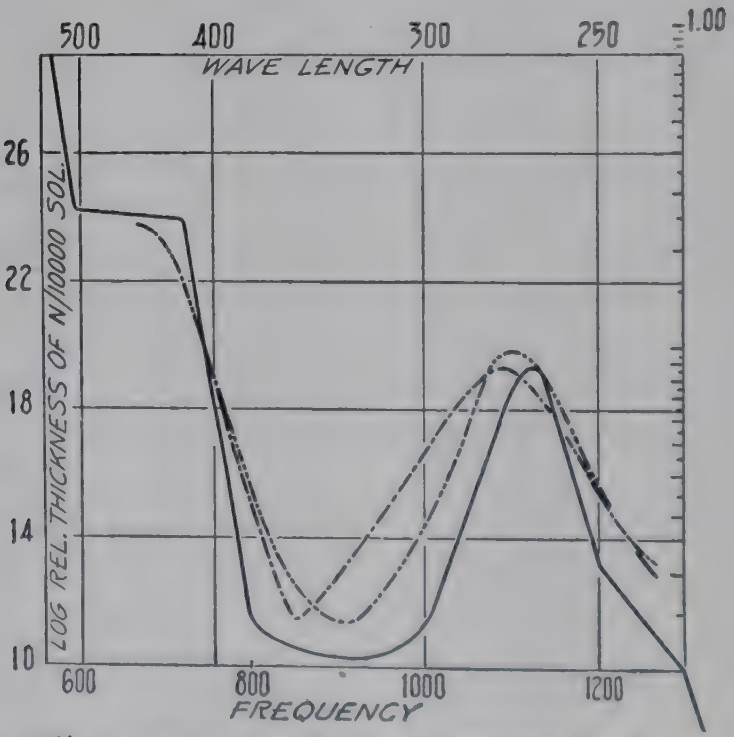


Fig. 7.54. Absorption spectrum of phenylazophenol in alcohol (—— Tuck [*C193*]); (— - — Hantzsch [*C96*]); (— - - - — Robertson [*C168*]).

photographic density is not produced at different wavelength values by equal transmission, and in the absence of a photometer or comparison series one cannot do much more than accept the wavelength position of the bands from the earlier work, and this may often be in error.

Practically all the data that have been published in the last twenty-five years have been of an accurate quantitative nature, but the lack of agreement as to the proper ordinate or abscissa often makes the exact interpretation of the data uncertain. One finds such terms as extinction, absorption, transmittancy, absorption coefficient, extinction coefficient, specific extinction, specific transmissive index, and many others as expressions for the relation log I_0/I (or kcd), and in other cases the same terms for k, log k, or molecular extinction (ϵ). In the abscissa terms one finds a division of opinion between the use of wavelength or frequency and in each of these divisions a further subdivision as to whether wavelength should be expressed as angstroms or millimicrons and whether frequency should be expressed as wavenumber (cm^{-1}) or true frequency. Many workers in a desire to conform to all schools of thought have included abscissa values in wavelength, wavenumber, and frequency values on the same figure (*B29*). (See Fig. 9.2.)

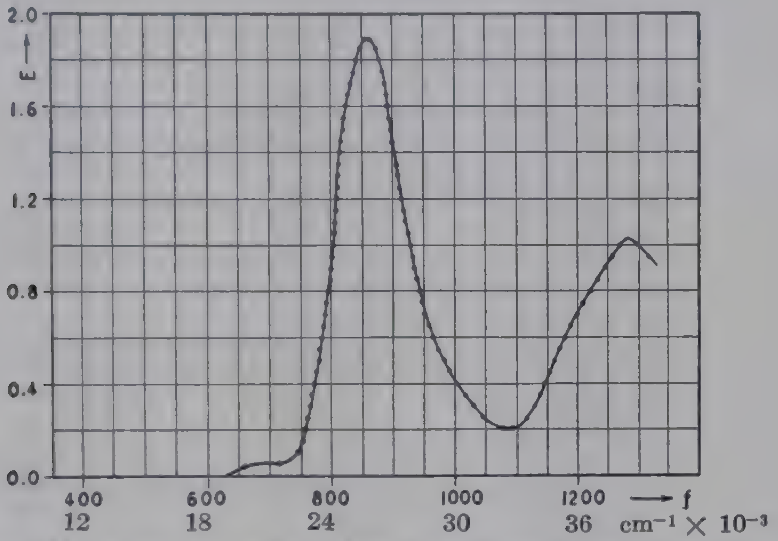


FIG. 7.55. Absorption spectrum of *p*-phenylazophenol in alcohol (Brode [*C20*]).

In the field of emission spectra, angstrom units have become so thoroughly accepted that no change or alternation seems either likely or desirable, although wavenumbers are important in this field, and one of the extended spectrum tables (*A77*) lists the lines both by wavelength and wavenumber. For the analysis of the spectrum into its terms and series it is essential to have the data in wavenumber or frequency rather than wavelength form. In the field of absorption spectra the presentation of data in a frequency form is essential to the complete analysis of the curves. It often happens that, if two or more bands occur in the same absorption spectrum and are due to the same resonating group, it can be shown on a frequency presentation that the observed bands are whole-number multiples of a fundamental frequency. This effect might be expected to be apparent for simple structures such as benzene (Fig. 8.2), but it is also apparent in complicated structures (Fig. 7.56) such as the dye Light Green SF Yellowish in which bands occur at frequency values of 472, 705, 945, and 1185 f. On the basis of 236 as a fundamental frequency, the calculated position of these bands would be 472, 708, 944, and 1180 f, corresponding to 2, 3, 4, and 5 times the fundamental frequency. It is interesting to note that in most of these complex structures the first multiple of a series is missing and those immediately following the missing component are more intense than other components. Other good examples of the multiple-frequency series in complex molecules are furnished by the absorption spectrum of potassium permanganate (Fig. 8.6) and by the cobalt halide series of bands in halogen acids (Fig. 8.5), in which band series are shown to exist as multiples over an extended range.

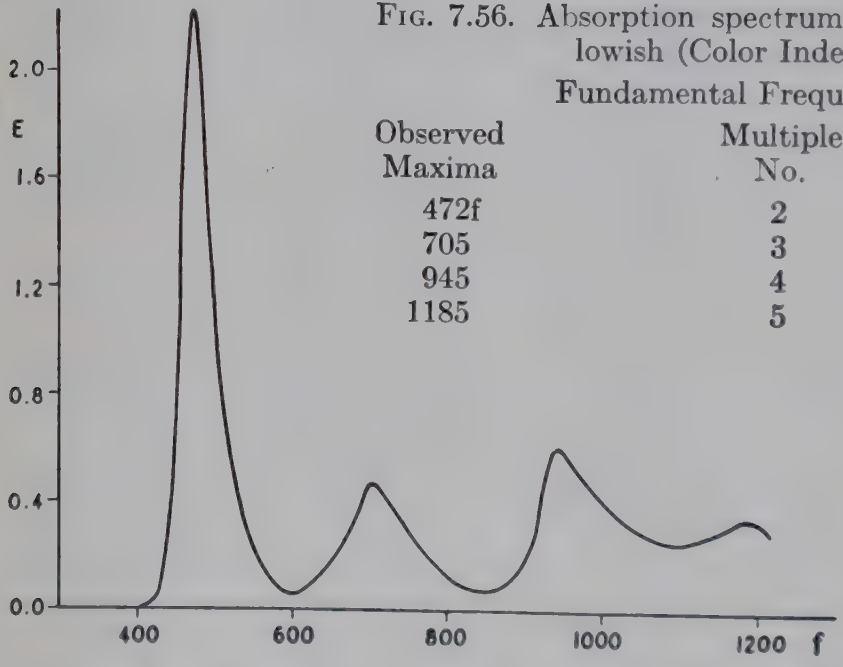


FIG. 7.56. Absorption spectrum of Light Green SF Yellowish (Color Index No. 670).

Fundamental Frequency = 236 f

Observed Maxima	Multiple No.		Calculated Maxima
472f	2	(× 236) =	472f
705	3		708
945	4		944
1185	5		1180

The majority of observations in absorption spectra studies have been made with prismatic instruments, and, as such, the dispersion is more nearly linear on a frequency rather than a wavelength scale. Hence, on a frequency scale the slit width, error in measurement, and the like are nearly constant throughout the curve. It is recommended that all absorption spectra determinations, therefore, should be recorded in frequency rather than wavelength abscissa values. It is probable that little change can be expected in the recording of visual data used by color analysts, and many visual instruments are built with calibrations in wavelength rather than frequency. In the recording of visual color in wavelength values it is desirable to use millimicrons ($m\mu$) rather than angstroms (A) since the accuracy of the measurement of wavelength values of absorption or reflection curves does not justify the greater accuracy indicated by the use of the angstrom notation. The millimicron may be defined as equivalent to 10A or as 10^{-9} meter. In our systems of numerical nomenclature we use milli- to indicate a thousandth and micro- to indicate a millionth; therefore a millimicron, or $m\mu$, is a thousandth-millionth of a meter, or 10^{-9} meter. There has been a tendency to assume that micron should indicate a thousandth of a centimeter, and the expression for the unit equivalent to 10 angstroms would thus become a micromicron, $\mu\mu$, which is not a correct use of the term micron. It should be remembered, however, that in articles where the symbol $\mu\mu$ occurs it is usually equivalent to $m\mu$.

The conversion of wavelength values (λ) to frequency values (ν) and wavenumber values (ν') can be accomplished easily by means of the reciprocal relations

$$1/\lambda = \nu' = \text{wavenumber}$$
$$c \cdot 1/\lambda = c \cdot \nu' = \nu = \text{frequency}$$

where c = the speed of light, or 2.99796×10^{10} cm per sec; λ = the wavelength; and ν' = the wavenumber in centimeters per second. For absorption spectra measurements the accuracy of determination is such that it is within the possible error to take c as 3 rather than 2.99796×10^{10}, and hence, to convert millimicrons to the accepted units of frequency and wavenumber. The following relation will be used:

$$\frac{1 \times 10^7}{\lambda \text{ in } m\mu} = \nu' \text{ in cm}^{-1}$$
$$\nu' \text{ in cm}^{-1} \times 3 \times 10^{-2} = \nu \text{ in fresnels (f)}$$

The unit of frequency, the fresnel (f), is thus equivalent to vibrations per second $\times 10^{-12}$. The choice of the fresnel as a unit for recording visible and ultraviolet data is very satisfactory in that the units are not unwieldy like the reciprocal centimeter values, and they provide the same numerical dimension as the millimicron within the visible range. The limits of the visible range in millimicrons are from 400 to 750, and, since the reciprocal of 400 multiplied by 3×10^5 equals 750, the fresnel units are of the same dimension for the visible spectrum, namely, from 750 to 400 f (Fig. 1.2). It follows then that any relation in one system may be equated to a similar relation in the other system; for example, if 500 $m\mu$ = 600 f, then 600 $m\mu$ = 500 f. The conversion from one system to another therefore is quite simple, and a table has been supplied (Table X in the Appendix) for this purpose.

The generally accepted system for the recording of wavenumber of values in absorption spectra data is in cm^{-1} × 10^{-3}, although in many cases the values are recorded in cm^{-1}. It has been suggested that the unit for wavenumber be given the name *balmer* with the symbol "B," which would correspond to the unit *angstrom* (A) in the wavelength notation. The limits of the visible range in cm^{-1} are from 1300 to 2500 (13 to 25 × 10^3 cm^{-1}). The conversions from wavenumber values (ν' in cm^{-1}) to frequency values (ν in f) and wavelength values (λ in mμ) are given in Table X in the Appendix, page 611.

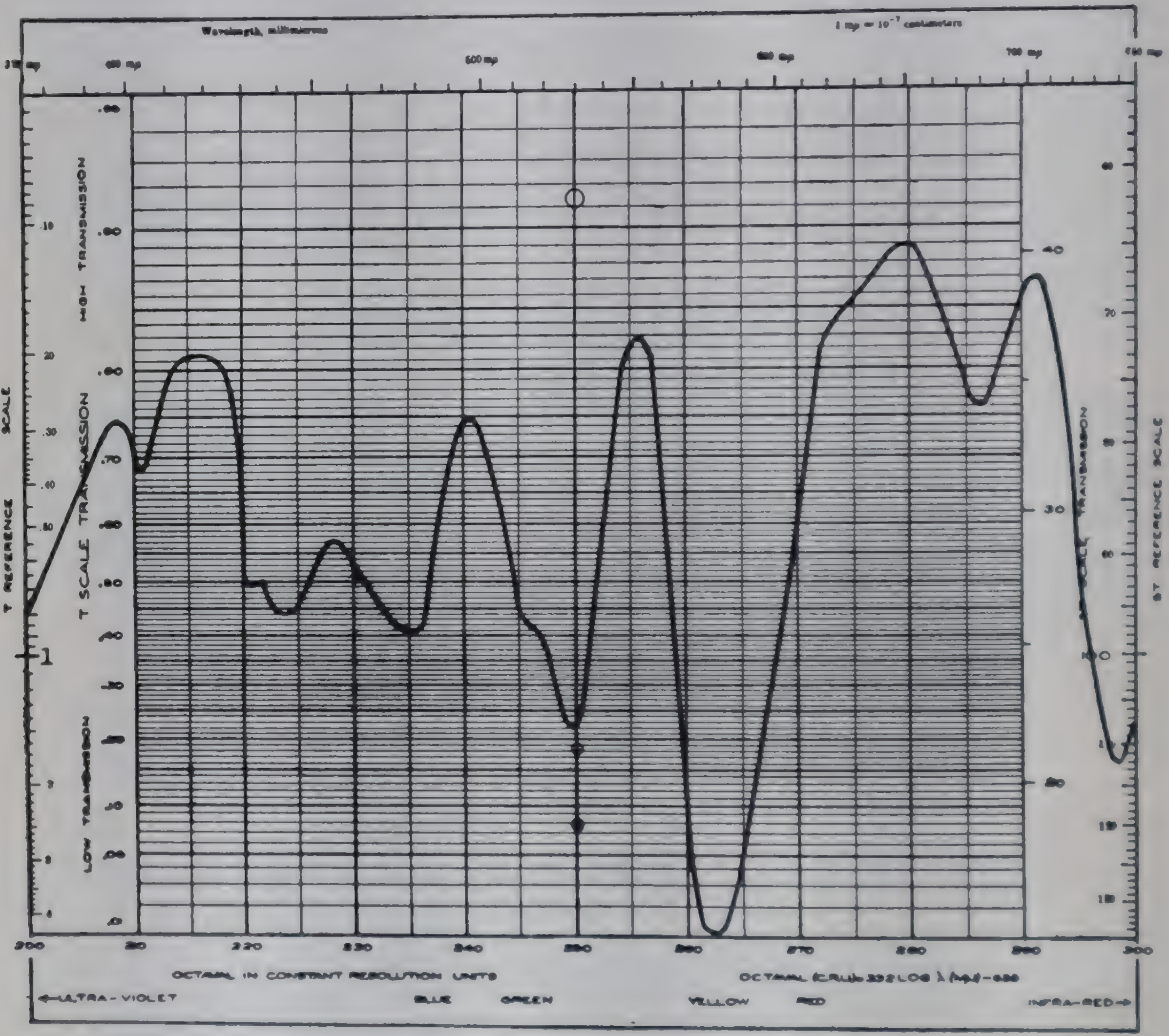


FIG. 7.57. Absorption spectrum of a neodymium filter recorded by a Hardy-General Electric spectrophotometer on an adjusted transmission and constant resolution unit system of abscissa and ordinate (Schurcliff *C181a*).

In order to establish a more uniform system of nomenclature and recording of absorption spectra data, it is suggested that an effort should be made to record all absorption spectra curves with extinction values plotted with an upward increase in numerical value, and that, as far as possible, frequency values be used as fresnel units (or wavenumber values be used as $cm^{-1} \times 10^{-3}$) and plotted with increasing values to the right. This would place the blue or ultraviolet on the right of the curve and the red or infrared at the left. To avoid confusion with wavelength notation it is suggested that wavelength values should be plotted with lower numbers on the right so that, as in the frequency curve, the blue or ultraviolet will be on the right and red or infrared on the left.

For the purpose of emphasizing certain portions of the absorption curve such as the hue of the transmitted color, it may be desirable to record absorption or transmission in other than a logarithmic system of extinction. In the description of color, it is the general practice to record in percentage transmission, placing the low-wavelength values on the left and the higher-wavelength values on the right and recording the percentage transmission with low numbers at the bottom and higher percentages at the top. This gives a curve which is inverted with respect to the usual method of recording absorption bands, inasmuch as absorption maxima are at minimum points on the curve.

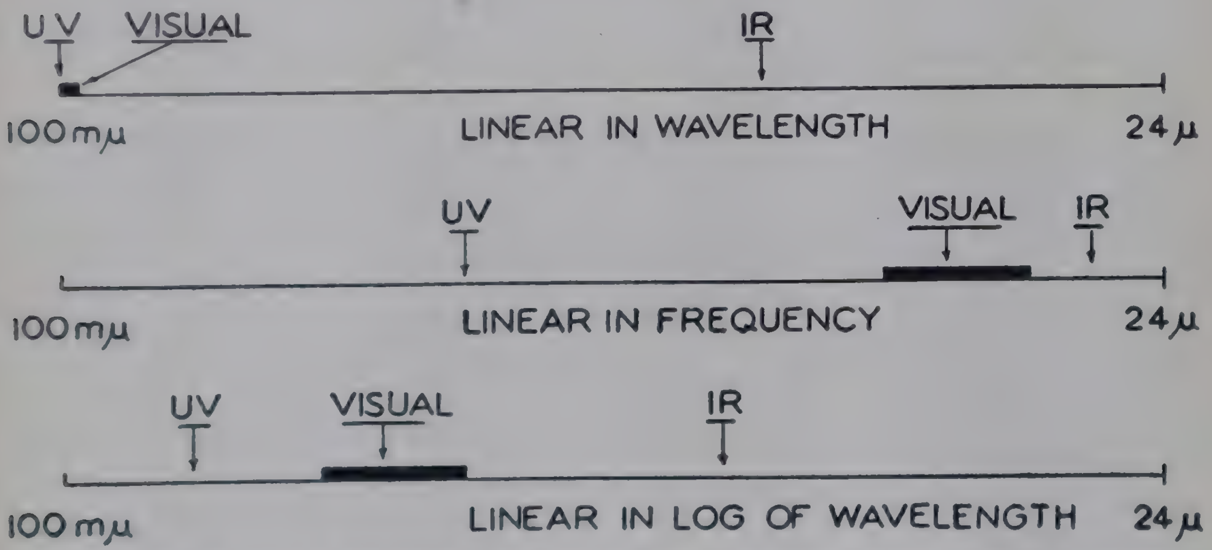


FIG. 7.58. Relation between linear recording of spectra in wavelength, frequency, and log of wavelength units. (UV-ultraviolet; IR-infrared) (Schurcliff *C182a*).

Other systems of recording color and absorption effects have been suggested, such as that devised by Schurcliff (*C182a*) for recording the high percentage transmission values and the low percentage transmission values on an extended scale, whereas the medium values are on a compressed scale (Fig. 7.57). Such a system of recording is useful to indicate both the visible color which is essentially a function of the region of high transmission, and the more accurate location of absorption maxima which are best observed in regions of low transmission. The use of logarithm paper for the recording of spectrographic data provides means for plotting in extinction and reading percentage transmission, and vice versa.

In Schurcliff's method of recording spectrophotometric data, he had used a logarithm-of-wavelength system for recording the abscissa data (Fig. 7.58). In this system he has used the logarithm to the base 2 of the wavelength so that multiple frequency values which would be in equal spacing on a frequency scale, bear the relation of 2, 3, 4, 5, etc., for successive harmonics on the logarithm-of-wavelength scale. The logarithm-of-wavelength scale provides a constant resolution unit in that the slit width at different wavelength values remains constant; hence, the notation c.r.u. has been used for the units recorded. (Table X-*D*, page 614).

The author admits that he has not always followed with exactness the above suggestions of recording spectrophotometric data either in this book or in his published papers. The data published in previous papers have been arranged in part to conform with the requirements of the laboratory in which the work was done. It has been felt worth while in this book to introduce some of the variations which are encountered in the literature so as to indicate methods and types of presentation of spectrophotometric data. In general, however, the suggested system has been followed, and it is hoped that eventually a more uniform system of spectrophotometric nomenclature and presentation may be adopted by the workers in this field.

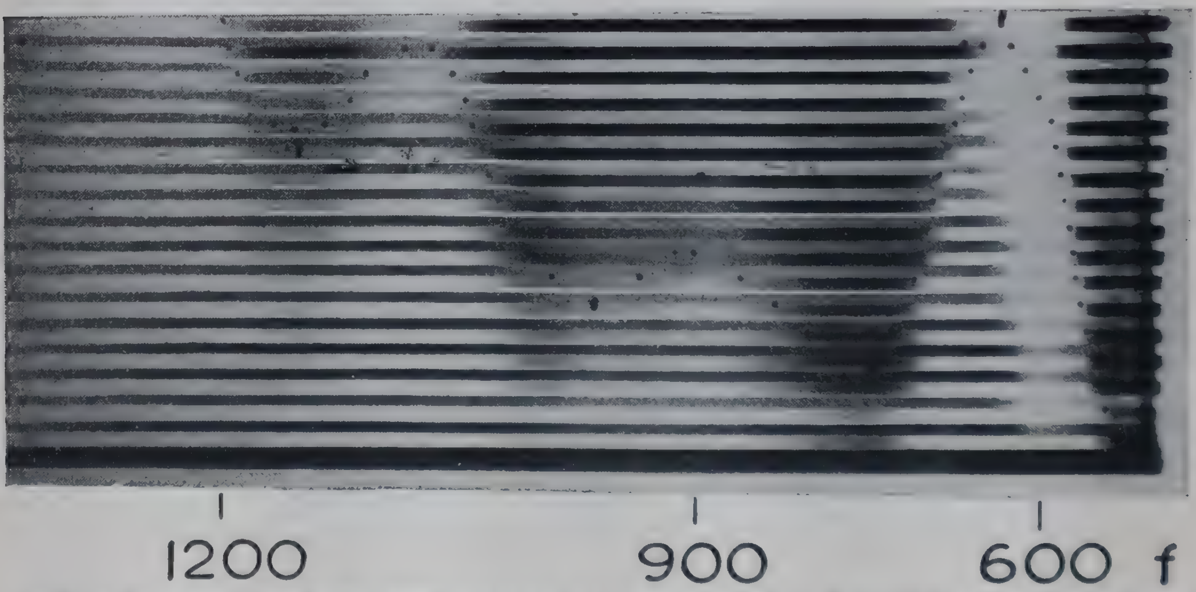


FIG. 7.59. Absorption spectrum of 2,5-dichlorophenylazo-β-naphthol (conc. = 0.216 cg per 100 cc, cell = 0.5 cm). N. Hilger sector photometer method with underwater spark illumination.

DETERMINATION OF ABSORPTION SPECTRA

In the determination of absorption spectra by visual means, there are usually two variable adjustments in the measurement; one may vary either the wavelength (or frequency) value, or one may vary the extinction value in order to determine a match point. In the ultraviolet instruments and other recording types, one of these two values is usually fixed in advance and a series of observations for match points is made by changing the other factor. In the sector or diaphragm photographic methods the sector or diaphragm is set for a definite extinction value and the wavelength is varied by taking a complete spectrogram (200 to 700 mμ) in the photograph, which is then examined for match points (Fig. 7.60). In the photoelectric method such as the Hardy, Hogness, or Harrison procedures, one sets the wavelength to a definite value and then varies the extinction to a match point. Where one has the choice of method, it is advisable to set the component which more nearly parallels the absorption curve and to vary the component which more nearly crosses the curve at right angles, i.e., if a sharp curve is to be recorded

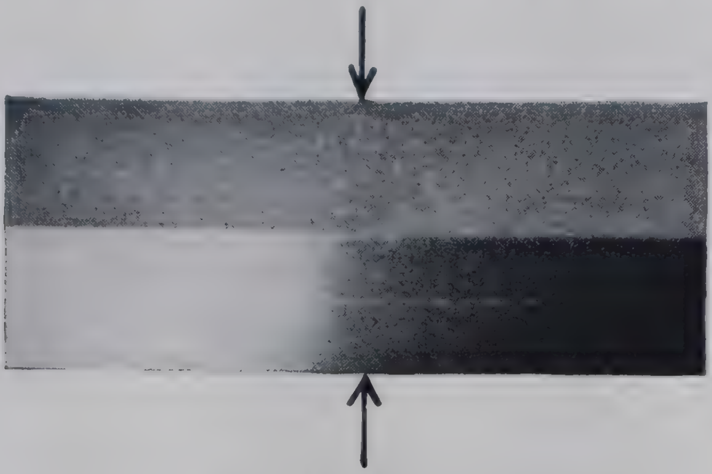


Fig. 7.60. Match point.

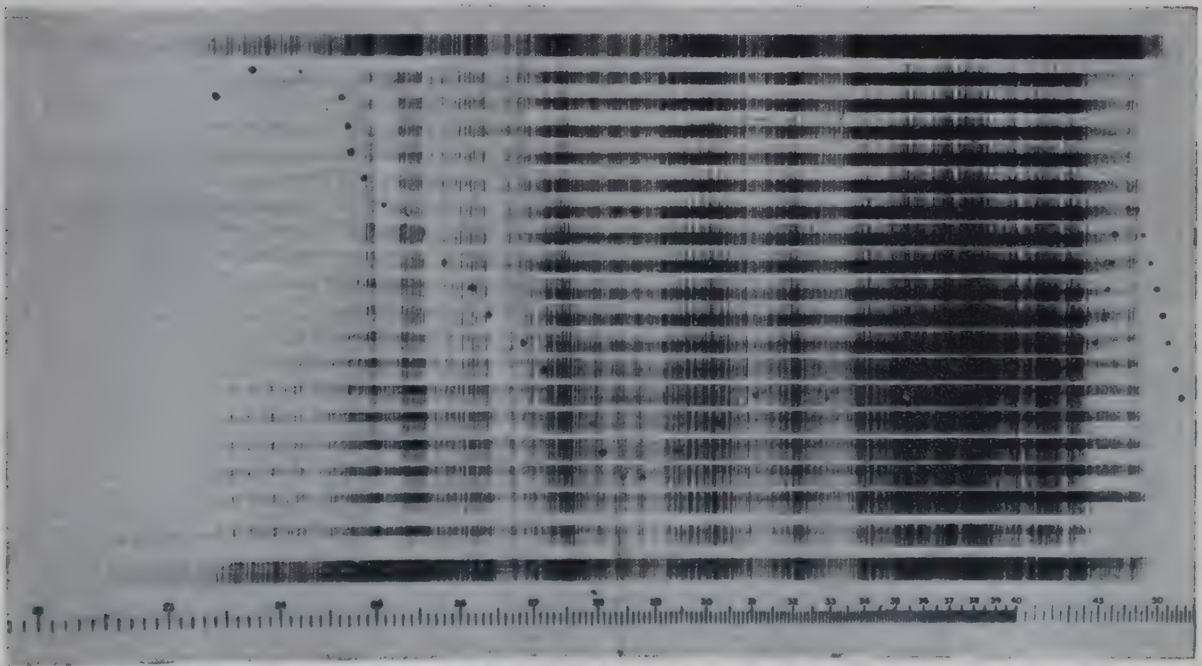


Fig. 7.61. Absorption spectra of phenylazo-β-naphthol in alcohol. Hilger sector photometer method with Fe-Ni arc illumination. **N**.

one would set the extinction to definite values and vary the wavelength, whereas if the curve is broad and flat one would set the wavelength at definite values and vary the extinction.

For purposes of reading an ultraviolet plate it is suggested that the negative be spotted (on the glass side) at the match points (Fig. 7.61) and then the frequency values be determined by superimposing a reading plate (Fig. 7.62). A convenient form of recording these values on a data sheet is illustrated in the experimental section (Fig. 12.37).

Spectrophotometers are usually standardized or calibrated by means of known filters of glass which have been compared on other instruments (Fig. 7.26). On account of the variable thickness and composition of glass it is difficult to select any glass as a standard, although curves are available on many of the Corning and Jena filters (*A35*). Three solutions which can be accurately prepared have been suggested as standards for calibration work. These are potassium chromate (Fig. 7.63), azobenzene (Fig. 7.2 and Table 7.1), and potassium nitrate.

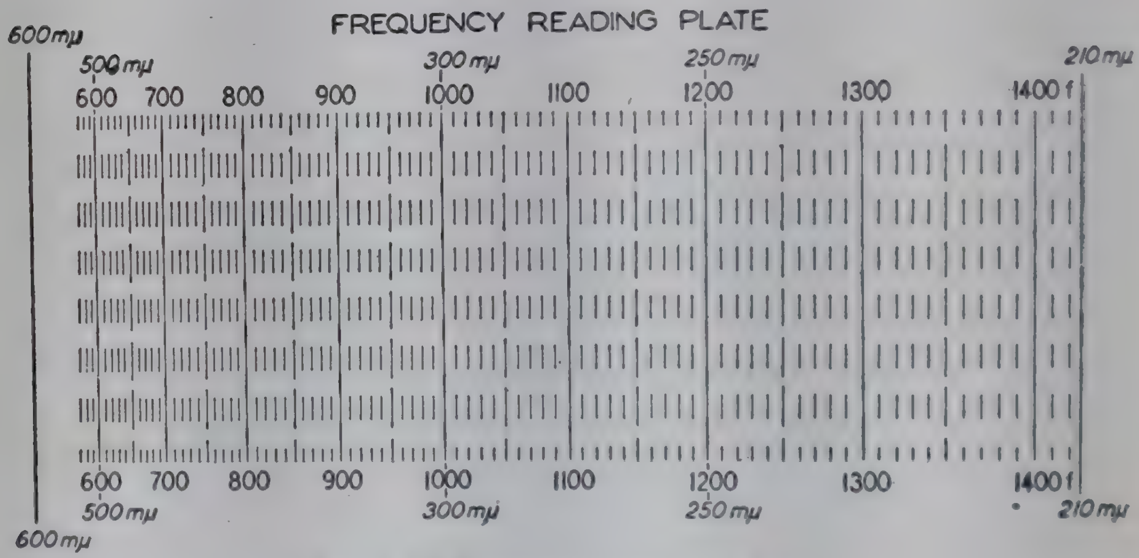


Fig. 7.62. Frequency reading plate.

A logarithm sector or graded wedge placed in front of the slit of a spectrograph which is illuminated by the light from an absorption cell, or the use of a wedge cell, will produce a qualitative indication of absorption band position and intensity which its quite satisfactory for many purposes and is used extensively at the present time (Fig. 7.4). Mees (*B56*) has published an atlas of absorption spectra of a number of compounds studied by this method. By the same method the relative sensitivity of a photographic plate can be indicated, assuming a uniform light source. A comparison of the plate sensitivity curve as against that of an absorbing material observed under equal illumination conditions will give a more accurate conception of the nature of the absorption band of the material.

The methods of quantitative absorption spectrum determination require a measurable light intensity, and hence are limited to the maximum extinction value that can be directly observed. Values of extinction greater than 3.0 are difficult if not impossible to obtain, and as a general rule extinction values should be measured between 0.5 and 1.8 in sector methods, or between 0.5 and 2.5 in diaphragm methods. For values which extend beyond these limits solutions of different thickness or concentration should be used, and if a change in concentration seems necessary the data should overlap sufficiently to test the validity of Beer's law for the compound. The number of observations or points on the curve that it will be necessary to determine will, of course, depend upon the kind of curve. For a simple azo dye such as *p*-phenylazophenol (Fig.

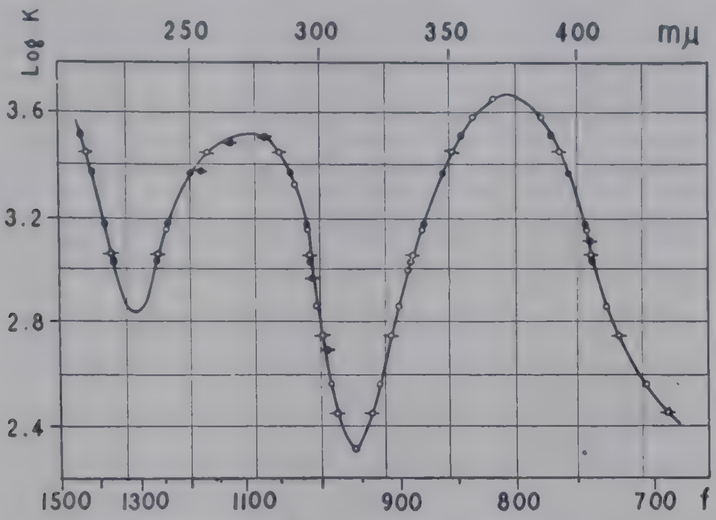


FIG. 7.63. Absorption spectrum of potassium chromate. Molar solution in 0.05*N* KOH. *d* = 1 cm; • sector method; –•–, photoelectric method; o, arc screen; –o–, spark screen. (Rossler-van Halban-Scheibe-Morton [*C145*, *C171*, *C180*, *C203*].) (See Fig. 12.38.)

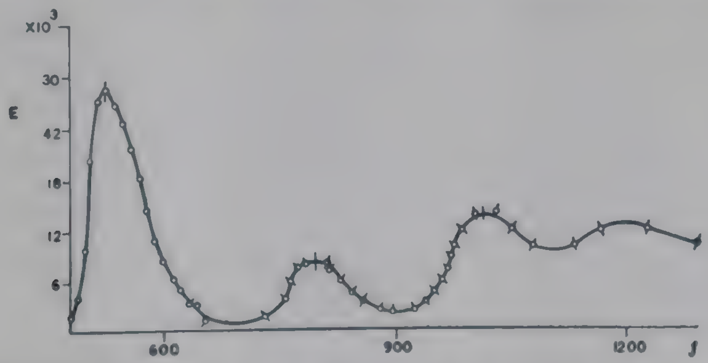


FIG. 7.64. Absorption spectrum of benzaurin in alcoholic KOH (1 mole dye to 60 moles of KOH). (o) *c* = 0.0421 gram per liter, *d* = 0.33 cm.; (♀) *c* = 0.0421, *d* = 1.0; (⚲) *c* = 0.0421, *d* = 0.33. (Gibbs and McNulty [*C154*].)

7.55) it can be seen that points closer than 0.1 extinction unit are unnecessary, whereas for a rare-earth glass sample (Exercise 8) it is necessary to have wavelength settings of about 2.5-mμ separation to determine the curve accurately (Figs. 7.57 and 7.29). It is therefore of some interest and importance in the publication of absorption data in molecular or specific extinction values to indicate the data points, concentrations, and cell thickness which were employed so that the accuracy of the observation can be judged by the reader. Some observers in the presentation of accurate data indicate such concentration and cell changes by various types of points on the specific or molecular extinction curve (Fig. 7.64). In general this is not necessary if concentration ranges and observational intervals are indicated.

LITERATURE

General

F. **Twyman** and C. B. **Allsopp**, "The Practice of Absorption and Spectrophotometry" (*B76*).

W. E. **Forsythe** and others. "Measurement of Radiant Energy" (*A23*).

F. **Weigert**, "Optische Methoden der Chemie" (*A99*).

E. S. **Miller**, "Quantitative Biological Spectroscopy" (*B57*).

Reference

Scheibe (*A81*), **Mees** (*B56*), **Ley** (*B46*), **Lowe** (*B51*), S. **Judd Lewis** (*B44*), **Gibson** (*B22*).

CHAPTER VIII

RELATION BETWEEN MOLECULAR STRUCTURE AND ABSORPTION SPECTRA

Analysis of Spectra of Complex Molecules

In the section on band spectra in Chapter II it is indicated that one might expect extremely complex absorption effects from the polyatomic molecules.

The complexity of diatomic spectral analysis becomes, in appearance, very simple when one attempts any exact mathematical analysis of the more complex molecules. A few triatomic and higher molecules of symmetrical nature, such as carbon dioxide, carbon disulfide, formaldehyde, and phosgene, have yielded to some degree of analysis (Fig. 8.1), but although the very symmetrical benzene molecule gives a remarkably well-defined absorption spectrum in the vapor state (Fig. 8.2*a*), its spectrum has not been satisfactorily interpreted.

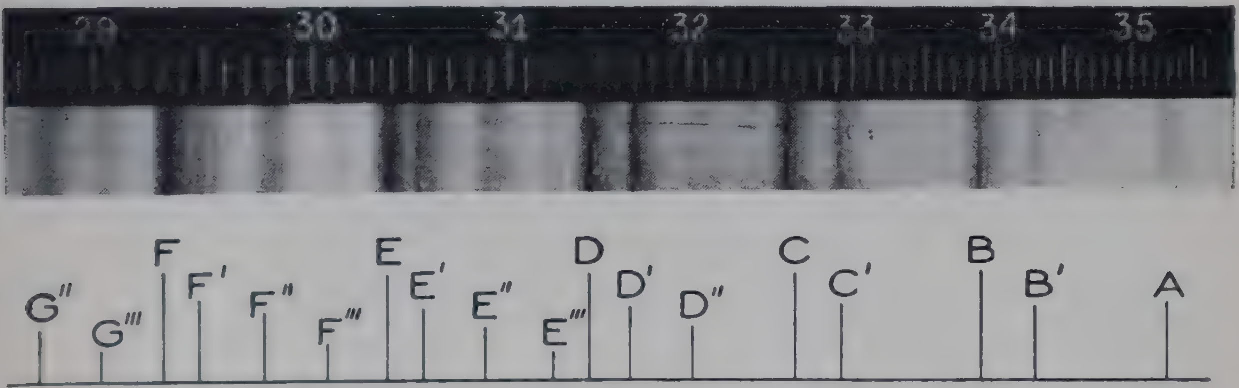


FIG. 8.1. Band spectrum of formaldehyde vapor. P. (After Henri and Schou [*C108*]).

In the earlier discussion of band spectra it was pointed out that the energy of absorption could be equated to the sum of the electronic, vibrational, and rotational energies (see page 144).

$$E = E_e + E_v + E_r$$

Rotational effects involve intraatomic binding and are observable in the far infrared (see Chapter X on infrared spectra). Vibrational bands (combinations of vibrational and rotational effects) will occur in the near infrared, and electronic bands will appear in the visible and ultraviolet portions of the spectrum.

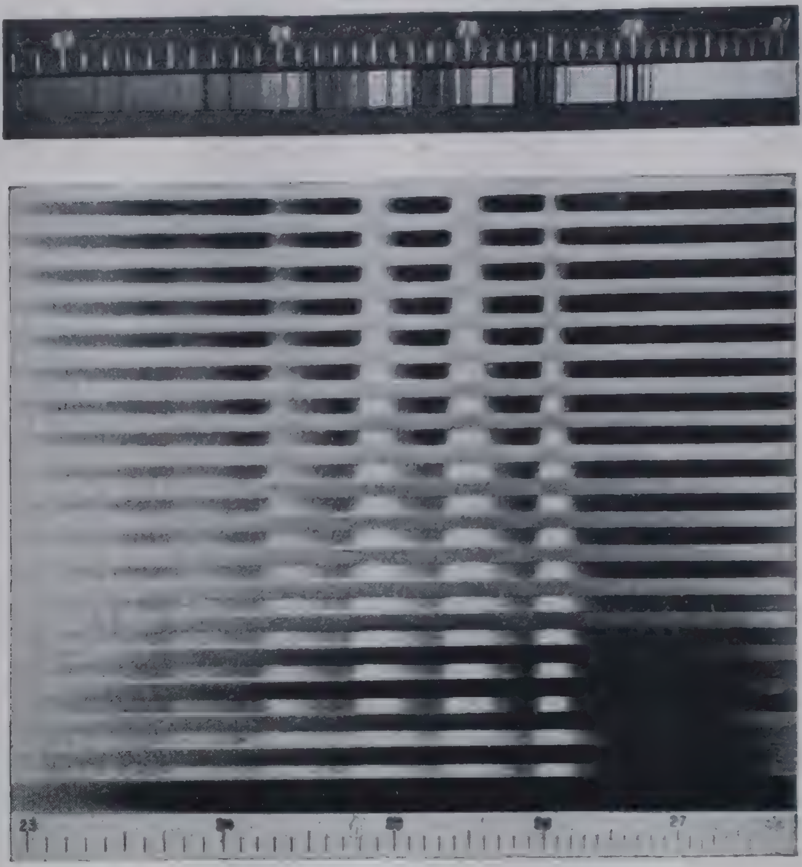


FIG. 8.2*a*. Band spectra of benzene: vapor (upper) **P**; solution in alcohol (lower) **N**.

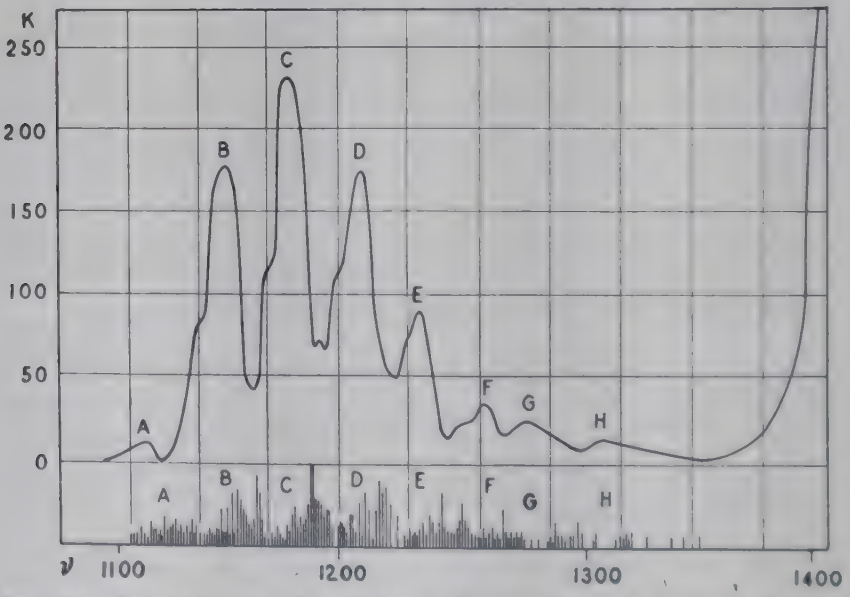


FIG. 8.2*b*. Graphical analysis of solution (upper) and vapor (lower) spectra of benzene.

It is apparent from a study of the absorption spectra of many of the highly complicated molecules that there is a transition from what one might call the atomic-electronic spectrum to a true molecular spectrum involving a resonance or vibration of the molecule as a whole. In these larger molecules the resonator or vibrator appears to act in accordance with the general laws involving harmonic vibration such as might be applied to resonators, strings, reeds, or other mechanically vibrating bodies. It must be admitted, however, that there is no sharp dividing line between atomic and molecular vibration as indicated, but for highly complex organic and inorganic resonators there is considerable value in a harmonic resonating theory. The nature of most molecular compounds

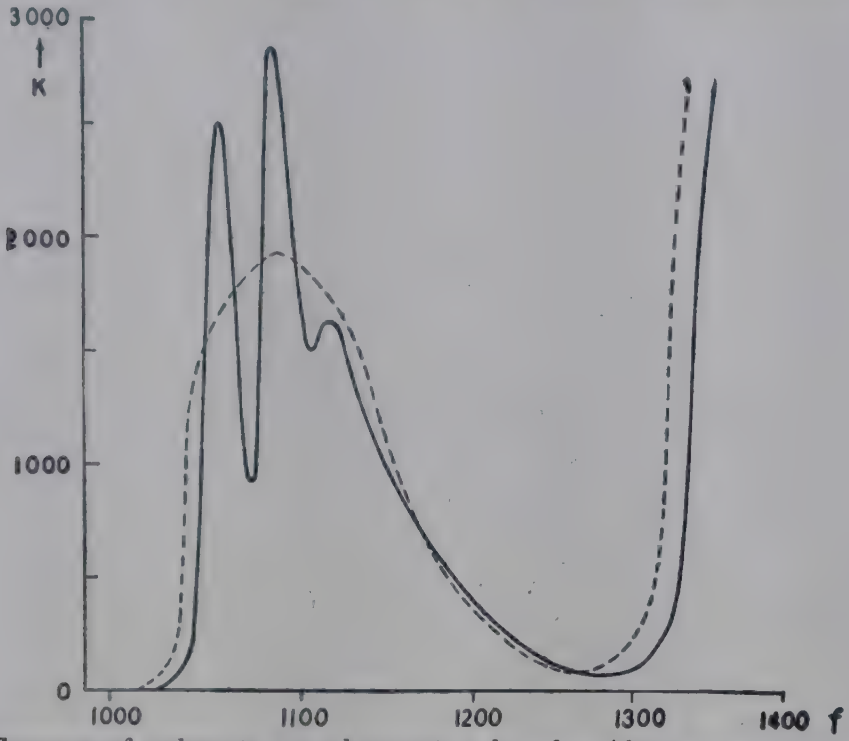


FIG. 8.3. Influence of solvents on absorption bands. Absorption spectra of phenol in alcohol (- - - -) and in hexane (———). (Klingstedt [*C117*].)

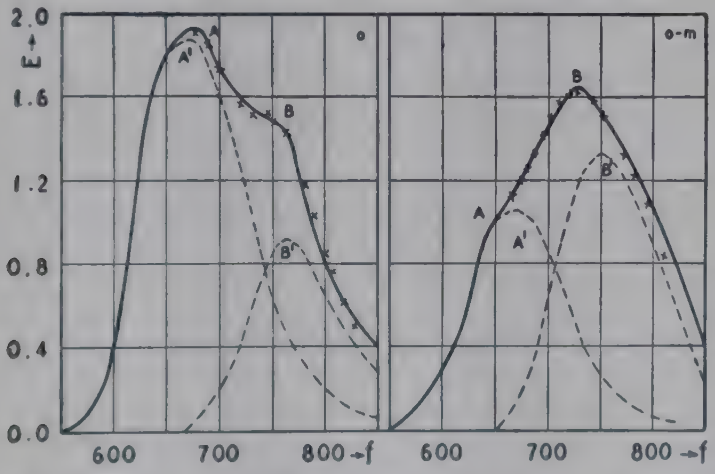


FIG. 8.4. The analysis of observed absorption bands into component curves. The above curves represent the absorption spectra of phenylazo-*o*-cresol (*o*), and *o*-tolylazo-*m*-cresol (*o-m*) in a 3 per cent aqueous solution of sodium hydroxide. The x marks on the graphs indicate values obtained from the addition of the component bands A' and B'. (Brode [*C22*].)

precludes emission spectra, so that our discussion in this field will be confined to absorption spectra.

The recording of absorption spectra of complex molecules on a frequency scale will, in general, show a simple relation between the bands if two or more are present. The seven bands of benzene (Fig. 8.2) show a uniform separation so that they could be considered as harmonics of a fundamental vibration of 30.2 f (See Table 8.3), although a more exact analysis of the line absorption spectra in the vapor state indicates a more complex harmonic system. The difference between the absorption spectra of benzene in the gaseous state and in solution is largely due to the modifying and dampening effects of the solution. The close proximity of the benzene molecules prevents an unhindered vibration so that the average frequency of vibration will be recorded as a maximum with a decrease in intensity on each side of this frequency. This averaging effect is more marked in polar than in nonpolar solvents (Fig. 8.3).

The averaging effect produced by solution interference and molecular irregularity, in reality, results in a simplification of the spectral data, although the band widths are such as to overlap in nearly all cases. The overlapping of bands does not always prevent a reasonably accurate analysis of the component structures and application of the data.

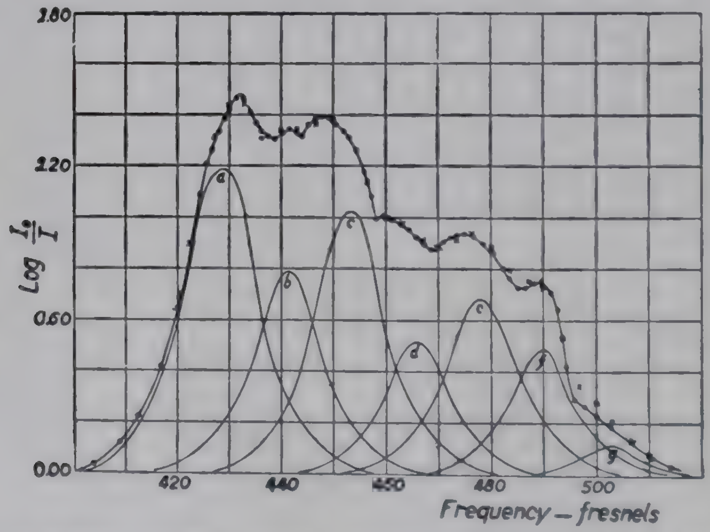


FIG. 8.5. Absorption spectrum of cobalt chloride in concentrated hydrochloric acid and its analysis into component bands (Brode [*C17*]. o = observed; x = calculated.

Band envelopes, which comprise two or more component bands, can be resolved into their component structures by mathematical procedures as well as by a somewhat simpler though not so accurate procedure of combinations of series of symmetrical curve forms (*C210, C212*).

The complex band of cobalt chloride, in concentrated hydrochloric acid as a solvent, has been shown to consist of a number of component parts (*C17, C47*) Fig. (8.5) and has been resolved into its component

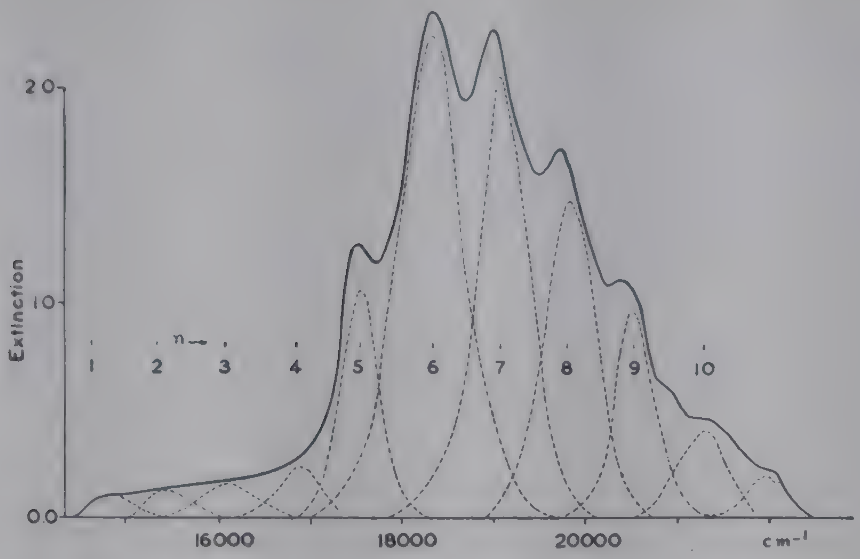
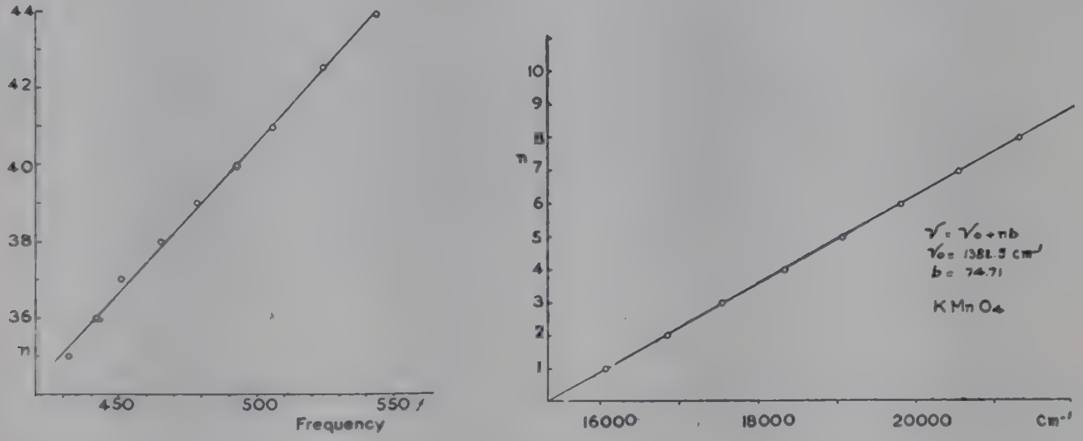


FIG. 8.6. Resolution of the absorption spectrum of an aqueous solution of potassium permanganate showing multiple frequency components. (Hagenbach and Percy [*C93*].)



a

b

FIG. 8.7. Plots showing linear relation between band multiple and frequency in the component band structures of cobalt chloride (*a*) (see Fig. 8.5) and potassium permanganate (*b*) (see Fig. 8.6).

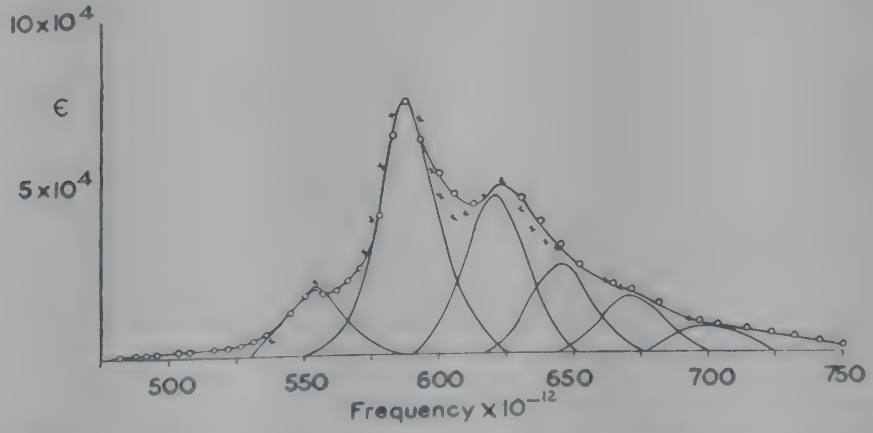


FIG. 8.8. Multiple frequency component band structures indicated in the absorption spectrum of a cyanine dye. (Sheppard [*C*182]).

structure. It can be shown that there is a uniform frequency separation of 12.28 f between adjacent members, and further, that the frequency of each component is a multiple of this frequency of separation. As an expansion of the system, more concentrated solutions of cobalt chloride were examined with an extension of the multiple frequency spacing to the fifty-seventh harmonic. A further examination of the bromo and iodo derivatives of cobalt in their corresponding concentrated halogen acid solutions revealed a similar system with multiple frequency differences (Fig. 8.9). The differences were lower in accordance with an increase of molecular weight of the halogen complex, but the multiple values for the first and the intense bands remained the same. All these separate smaller bands may thus be considered as the components of larger bands, and these larger bands in turn possess multiple relations with other principal bands.

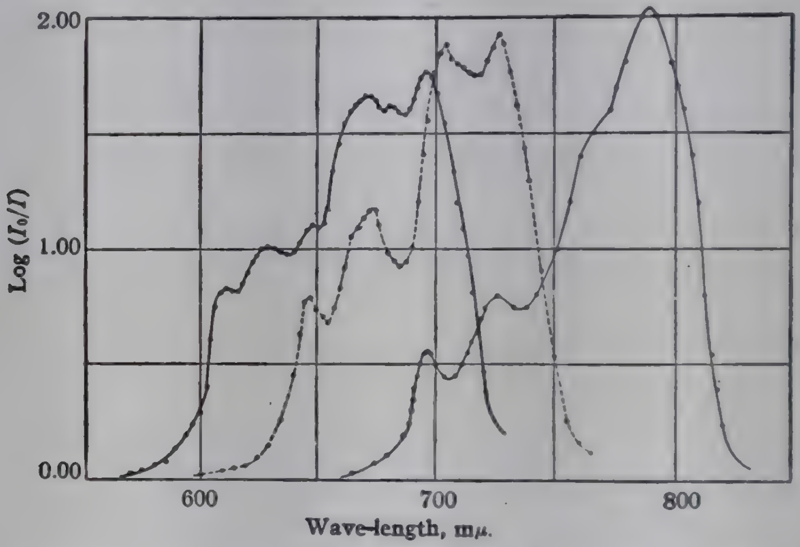


FIG. 8.9. The absorption spectra of cobaltous halides in their halogen acids: heavy line, $CoCl_2$ in HCl; dotted line, $CoBr_2$ in HBr; light line, CoI_2 in HI. (Brode [*C17*, *C47*] and Morton.

WEIGHTING EFFECTS IN RARE EARTH AND INORGANIC COMPOUNDS

Although there is a marked similarity in the spectra of the rare earths and other inorganic materials such as the cobalt salts, the absorption spectra of the rare-earth compounds deserve separate consideration. From a study of the electron assignments of the atoms it is to be noted that the rare earths possess an incompleted 4*f* group in the *N* shell while possessing at the same time completed 5*s* and 5*p* electron groups in the *O* shell and the same outer configuration in the *P* shell. As might be predicted, the absorption bands of the rare earths undergo considerable narrowing and sharpening as the temperature is lowered so that at liquid-air temperatures the bands may be less than an angstrom in width (Fig. 8.10). At low temperatures the atom does not exist in higher states than the ground state, and hence some of the lines will disappear. The continuance of absorption at low temperatures gives some indication that the absorption is due to the atom rather than the molecule, except that the change of molecular composition, as is also true of other organic and inorganic molecules, results in a shift of the absorption bands, although this shift is not so pronounced at low as at high temperatures. Although there is some evidence that the absorption bands of the rare earths originate in the atom, it is also apparent that the bands are influenced by the atoms in combination with the rare earth, and the same effect is apparent in other inorganic color-producing elements. In the rare earths, the incompleted shell is well within the atom and protected from some of the surrounding influences by additional electron shells. The color, or light absorption, produced involves a transition from a higher level to this incomplete level. The addition of certain protecting groups around the atom in the form of anions serves further to protect and to prevent the external disturbance of the resonance or electron shifts. At lower temperatures, additional protection is afforded in the reduction of molecular vibration, and hence sharpening of the bands, since the energy jumps will become more uniform and constant with a reduction of the outside disturbing factors. (See Fig. 7.50.)

FIG. 8.10. Absorption spectra of praseodymium acetate at room temperature (top) and liquid-air temperature (bottom). Neon spectrum in middle. P.

If outside disturbing forces could be minimized, it would be expected that nearly line-like components of the band structure would be resolved in the spectrum. Cobalt chloride in concentrated hydrochloric acid is an example of this type. There is an apparent reaction of

$$CoCl_2 + 2HCl = [CoCl_4]^{--} + 2H^+$$

the cobalt being completely surrounded by the four chlorine atoms and the whole molecule acting as a single vibrating unit, in which the incomplete shell is buried within the molecule in the *M* or *N* shell. In a solvent consisting essentially of Cl^- and H^+ ions this tetrahalogen compound is quite free from outside influences and exhibits well-defined band structure (Fig. 8.5).

The change of the external mass or protecting shell of the vibrating nucleus without altering the mass of the inner atom produces quite a different effect from that produced in going from one member to another in the rare-earth series, where the inner mass is altered without changing the electron configuration or weighting beyond the partially filled shell. The changes in the spectrum resulting from addition outside the chromophore, or vibrating nucleus, rather than from changes within, may be classified as (*a*) changes in frequency, and (*b*) changes in intensity. From simple mechanical principles it would be expected that the mere weighting of a vibrating body would decrease the frequency with which the vibrating body oscillates (Fig. 8.11). The change in frequency of an absorption band towards lower values as the result of the addition of some weighting group, without the change in the spectral appearance, is evidence that the added group is directly connected to the vibrating nucleus and actually forms a part of the vibrating body.

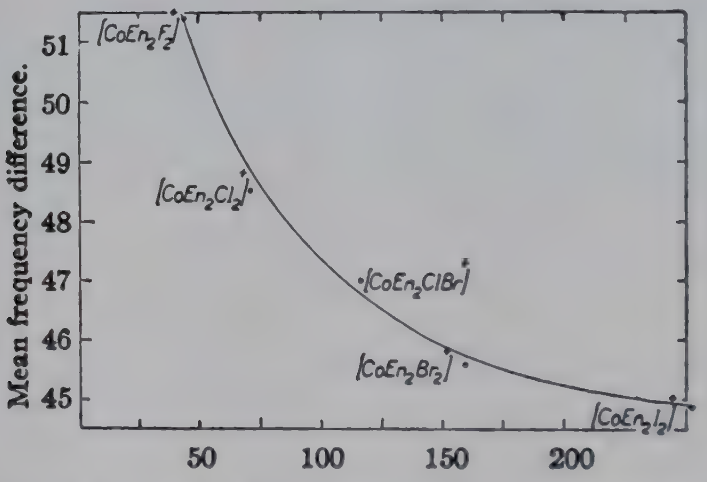
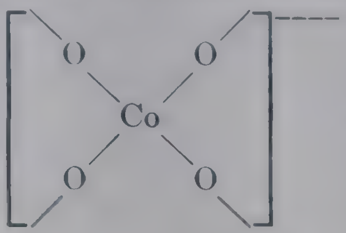


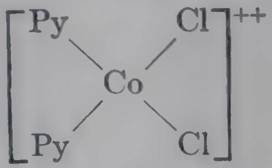
FIG. 8.11. Change of frequency difference between component bands, in the 1,6 series of $(CoEn_2X_2)X$, caused by a change of halogen substituent (Brode and Ernsberger [*C37*]).

It does not necessarily follow that all elements or radicals transmit their weighting effects to the nucleus to which they may be attached. There are many groups such as the methylene (—CH_2—) which act as a cushion or shock absorber by failing to transmit vibration from one part of the molecule to another, whereas an ethenylene linkage (—CH═CH—) not only transmits vibrational effects but also, in many cases, acts as a resonating or amplifying system to enhance the spectrum intensity. Such elements as oxygen, nitrogen, and sulfur often act as weighting elements in themselves, but the effects of groups attached to them are not transmitted. Examples of this type are shown in the lithium, sodium, potassium, rubidium, and cesium series of cobalt glasses where the chromophoric complex is accepted as

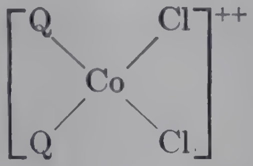


· 4Na⁺ (Li . . . Cs)

and where the change in the metal from lithium to cesium does not appreciably affect the frequency of the vibrating system. A substitution, however, of sulfur for oxygen causes a marked shift to lower frequency (*C24*). A similar situation is presented by the cobalt pyridinium and quinolinium halides in which the absorption bands of the two salts



· 2Cl⁻ and



· 2Cl⁻

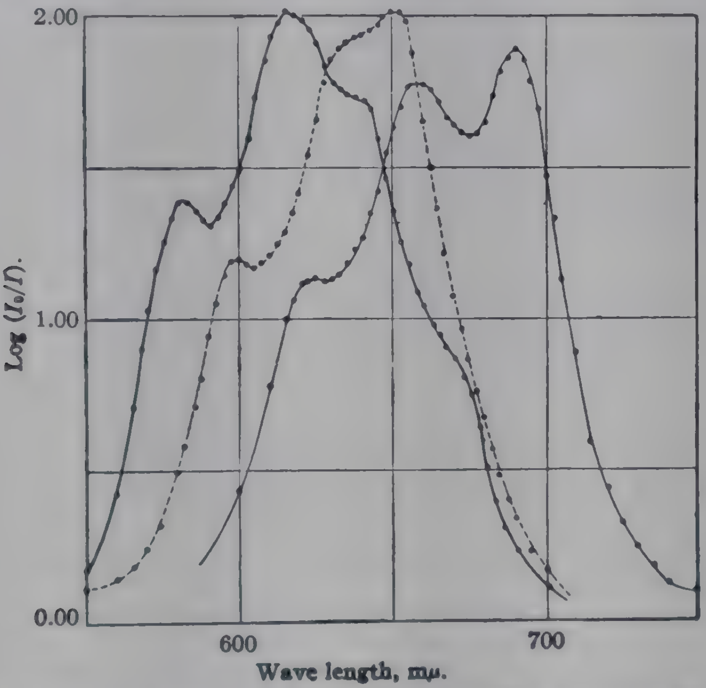
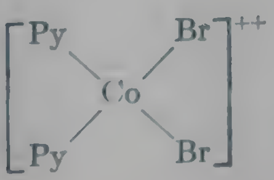
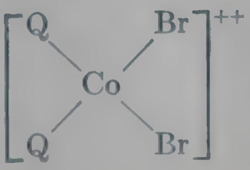


FIG. 8.12. The absorption spectra of cobaltous halides in quinoline, ———, $CoCl_2$; – – – –, $CoBr_2$; ———, CoI_2. Nearly identical curves were obtained from cobalt quinolinium halides in quinoline and cobalt halides and cobalt pyridinium halides in pyridine. (Brode [*C25*].)

(Fig. 8.12) have approximately the same frequency, whereas the introduction of bromine in place of chlorine in each of these compounds to produce



· 2Br⁻ and



· 2Br⁻

results in a weighting shift since the halogens are directly attached to the cobalt, whereas the additional carbon and hydrogen atoms in quinoline are attached through the nitrogen and not directly to the cobalt.

The second (*b*) type of effect resulting from the change of exterior weighting of a chromophore involves the relative intensities of the bands which are components of the absorption spectrum. This effect is involved in relative intensities of components and is apparently a function of electronic forces more than of mass, the greatest effects being observed in those compounds which have their nuclei or conjugated center at a greater distance from the chromophoric center. In comparing the absorption spectra of the cobalt halides (Fig. 8.9) it is to be noted that, in addition to the shift of frequency due to a weighting effect, there is also an enhancing effect involving a concentration of the major intensity

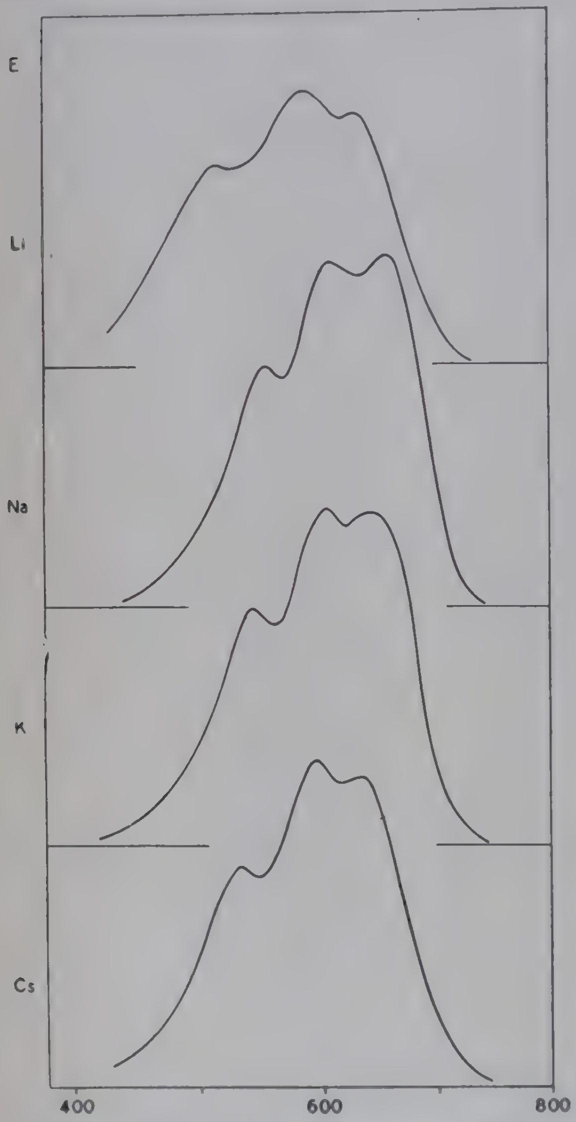


FIG. 8.13*a*. Absorption spectra of cobalt oxide in lithium oxide-, sodium oxide-, potassium oxide-, and cesium oxide-boric oxide glasses. (Brode [*C24*].)

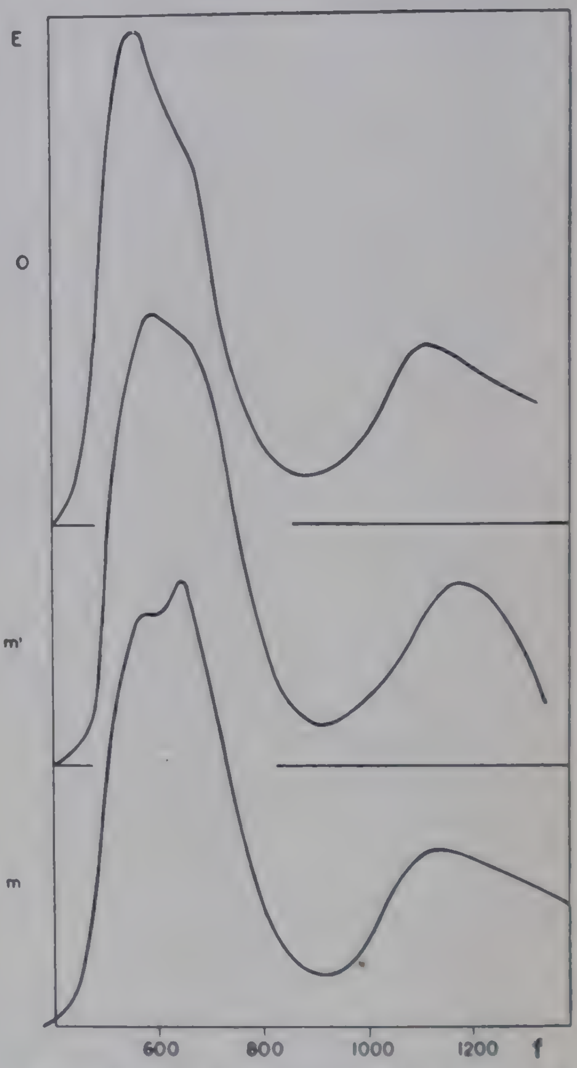


FIG. 8.13*b*. Absorption of *o*, *m'*, and *m*-methylphenylazophenol in 3 per cent NaOH solution. (Brode [*C22*].)

in the first component of the series of bands. The same effect is to be noted in the derivatives of phenylazophenol (*C18*) (Fig. 8.13*b*) in which a shift of a methyl, nitro, or halogen group from *meta* to *meta′* to *ortho* positions in the ring results in a corresponding shift of the intensity center to the first or principal band. The shift of intensity in the alkali oxide series of cobalt glasses is another example of the same effect (Fig. 8.13*a*). (See also Fig. 10.5–10.9 for similar effects in infrared spectra.)

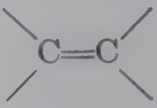
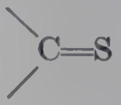
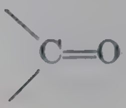
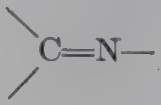
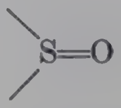
CHROMOPHORES

In the classification of colored or absorbing systems it is customary to ascribe to a certain part of the molecule the resonating effect which is considered responsible for the color, and such a group is known as the *chromophore* (*B30*). The groups given in Table 8.1 are generally included in a list of organic chromophores.

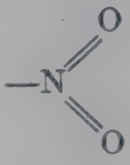
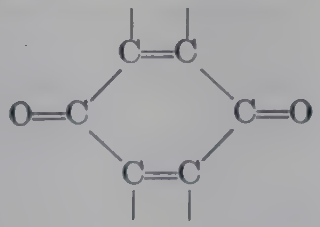
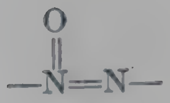
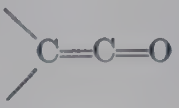
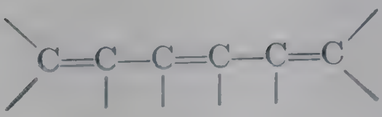
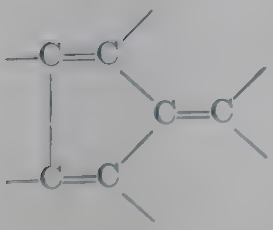
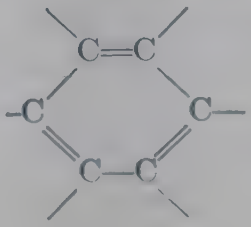
TABLE 8.1

IMPORTANT ORGANIC CHROMOPHORES

(*a*) *Simple*

	Ethylene		Thiocarbonyl
	Carbonyl		Azomethine
—N=N—	Azo		Sulfoxide
—N=O	Nitroso		

(*b*) *Complex* (*involving two or more simple chromophores*)

	Nitro		Quinone
 $-\overset{O}{\overset{\Vert}{N}}=N-$	Azoxy		Ketene (cumulative unsaturation)
	Divinyl ethylene (conjugated unsaturation) (polyethenylene)		
	Fulvene (branched conjugation)		Benzene (cyclic conjugation)

Chromophoric changes may be resolved into two effects, intensity and frequency shifts, which are described as follows:

(*a*) **Hyperchrome:** An increase in the extinction value of the absorption band. *The intensity of the color increases.*

(*b*) **Hypochrome:** A decrease in the extinction value of the absorption band. *The intensity of the color decreases.*

(*c*) **Bathochrome:** A shift of the absorption band towards the red (lower frequency). *The color deepens* (i.e., a change from yellow, to red, to purple, to blue, to green). (See Chapter XI.)

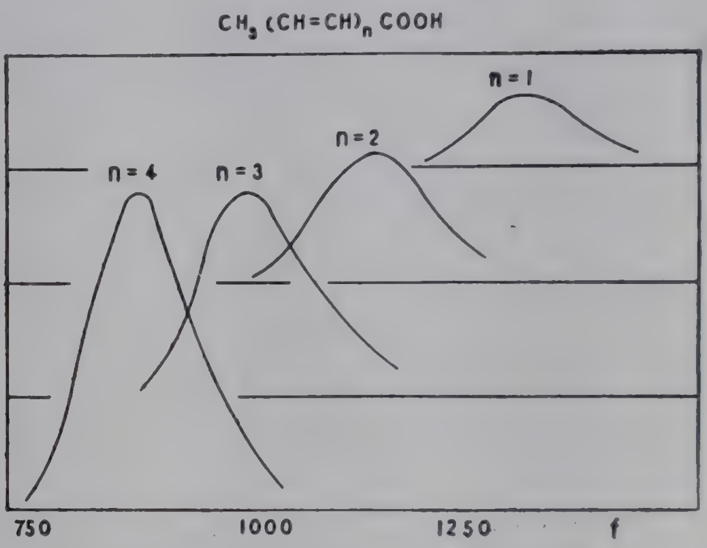


FIG. 8.14. Absorption spectra of unsaturated acids with conjugated ethenylene ($>C=C<$) linkages (Hausser [*C103*, *C104*]).

(*d*) **Hypsochrome:** A shift of the absorption band towards the blue (higher frequency). *The color lightens* (i.e., a change from green, to blue, to purple, to red, to yellow).

Many of the simple resonators or chromophores do not in themselves produce visible absorption. Ethylene, for example, has an absorption band at 1545 f (1950A) in the extreme ultraviolet, but the conjugated coupling of two or more ethylene radicals together results in both hyperchromic and bathochromic effects (Figs. 8.14 and 8.15). The actual effect seems to be more nearly a multiplication of resonance than addition. The carotinoid colors, such as those found in the carrot and tomato, are typical of a long chain of seven to thirteen conjugated double bonds.

Wizinger (*B79*) has suggested the use of an ionic formula for the representation of a resonating system, and this, in many ways, is more satisfactory than the more rigid chromophore formula. For example, in the representation of triphenylmethyl it is difficult to explain the intensification of color on the change from neutral to acid or alkaline solutions, but in the ionic formula the representation is not difficult (Fig. 8.16).

It would therefore appear that, in addition to the usual positive auxochromes, OH, OR, NH_2, NHR, NR_2, which cause color intensification

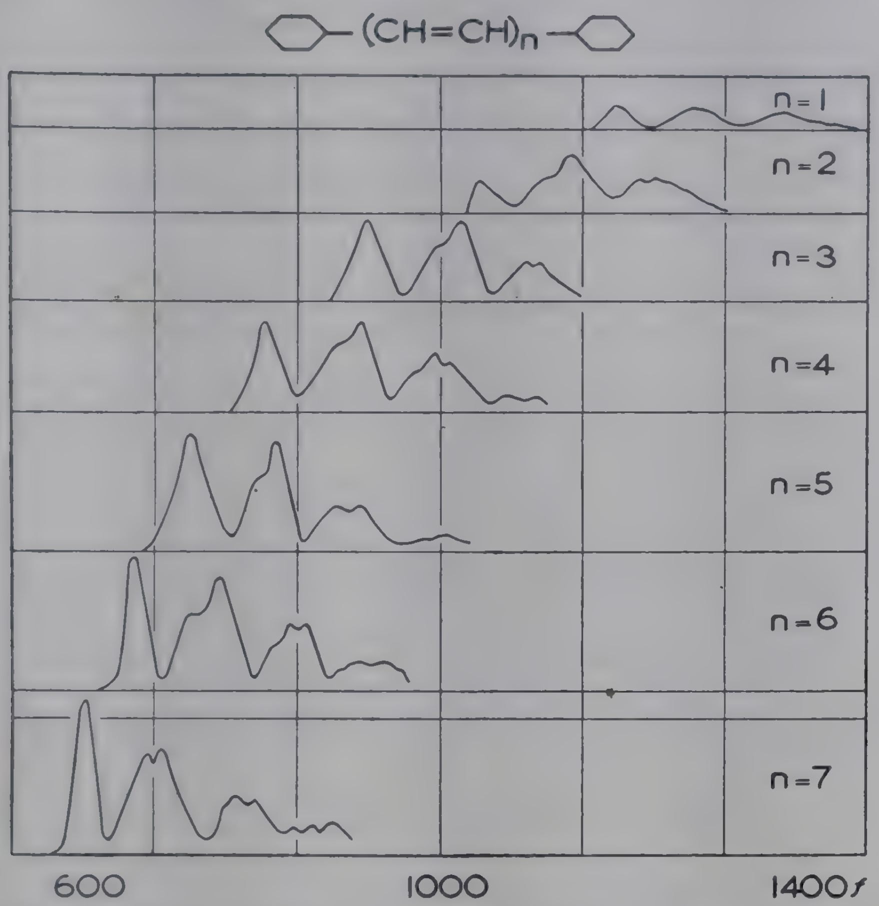


Fig. 8.15. Effect of conjugation in polyethylene diphenyl derivatives C_6H_5—$(CH = CH)_n$—C_6H_5 (Hausser [*C104*]).

and bathochromic effects (color deepening) in positive ions with a coordinated unsaturated central atom or resonating group, there are negative auxochromes, such as the NO, NO_2, CO, CN, SO_2, and N═N, which

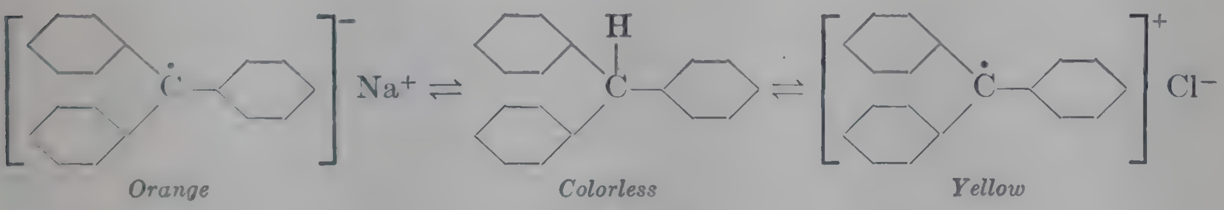
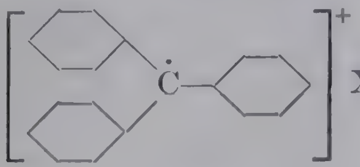


Fig. 8.16

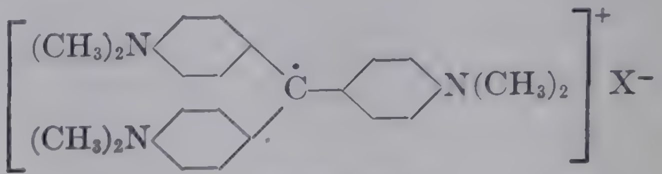
produce hyperchromic and bathochromic effects in negative ions with a coordinated unsaturated central atom or resonating nucleus.

One might further extend this auxochrome-ion theory to include amphoteric auxochromes such as the C═C linkage which can act as an auxochrome or resonating amplifier in either positive or negative ions.

The examples of negative and positive auxochromes in Fig. 8.17 will serve to illustrate these effects.

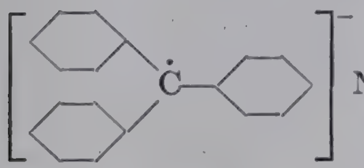


Yellow

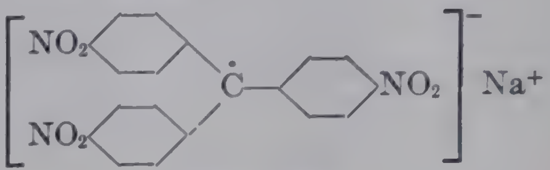


Intense violet

POSITIVE AUXOCHROME



Orange



Intense violet

NEGATIVE AUXOCHROME

FIG. 8.17

Whether one accepts the ionic, chromophore, or electron shift formulas for the production of color they are all merely graphical means of representing the same color effect. It should be remembered that the writing of a compound in a quinoid formula does not of necessity indicate that no benzene ring is present, but rather that it is capable of resonating between that and an ionic benzene structure. In the representation of the formulas of many dyestuffs and other absorbing groups we will use quinoid structures since they are the accepted form and are more easily visualized.

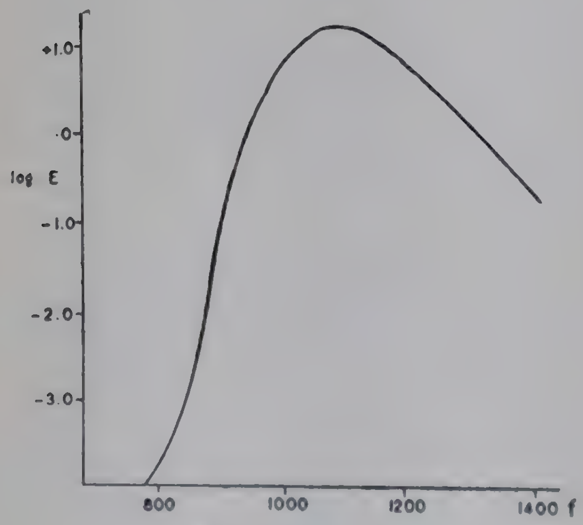


FIG. 8.18

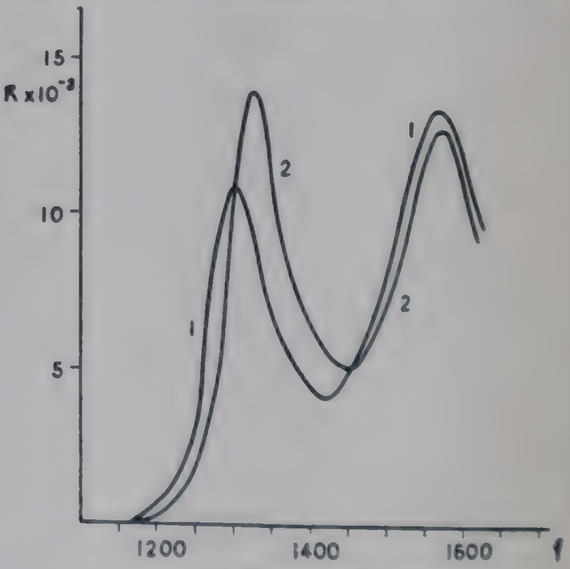


FIG. 8.19

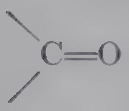
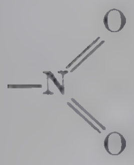
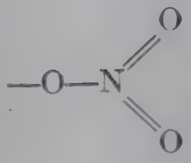
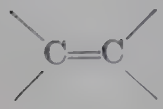
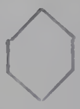
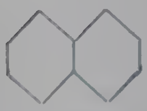
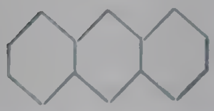
FIG. 8.18. Absorption spectrum of acetone.
FIG. 8.19. Temperature effect on absorption spectrum of the iodine ion in NaI-H_2O solution (Scheibe [*1*,20°; *2*, 70°] [*C176*, *B70*]).

For some of the simple chromophores such as the carbonyl it is possible to assign a certain frequency of absorption (Fig. 8.18) as characteristic of this resonating group although it must be remembered that the attachment of radicals to the chromophore will result in a shift of frequency and intensity. The simple colored ions can also be assigned certain absorbing centers or bands as indicated in Table 8.2.

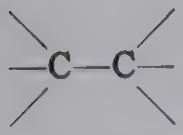
With ionizable substances or those which undergo a chemical reaction with the solvent there will be marked effects upon solution, dilution, or change of temperature (Fig. 8.19).

TABLE 8.2

WAVELENGTH AND FREQUENCY VALUES FOR CHROMOPHORIC GROUPS

Group	λ	ν	ϵ
	280 mμ	1076 f	
—O—H	186	1615	
—S—H	227	1325	
	366	820	
	302	994	
	180	1660	
	268	1120	39
	311	964	280
	476	800	9700

The effects of solvents may be divided into two classes: that in which a chemical combination takes place with the compound, and that in which the frequency of the absorption band is influenced by the polar nature of the surrounding medium without any actual chemical combination with the solvent material (Fig. 8.20).



It has been shown that in the simple C—C bond there is no apparent absorption in the visible or near ultraviolet as a result of the electronic resonance possibilities of the C : C linkage. Infrared and Raman spectra are produced by simple compounds with such C—C linkages, but these spectra are characteristic of the simple linkage and not of the molecular resonance as a whole,The —C— linkage, since it does not transmit resonance vibration from one resonator to another to any extent, can act quite satisfactorily as an insulator between two chromophore groups. This is especially true of two methylene groups: —CH_2—CH_2—.

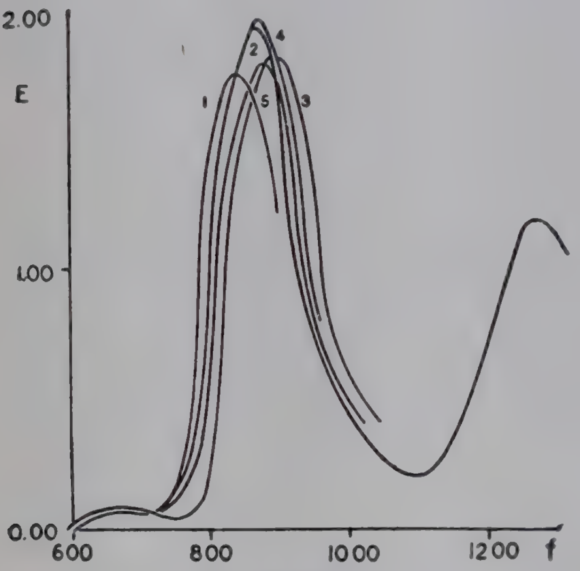


Fig. 8.20

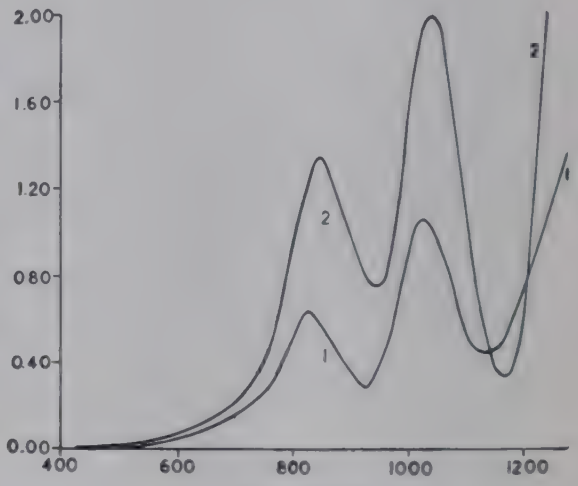


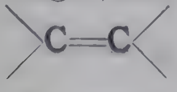
Fig. 8.21

Fig. 8.20. Effect of solvents on the absorption spectrum of benzeneazophenol. 1. Pyridine. 2. Methyl alcohol. 3. Petrolatum. 4. Ethyl acetate. 5. Benzene. (Brode [*C20*].)

Fig. 8.21. Absorption spectra of iodine in ethyl alcohol (1) and in KI solution (2). (Brode [*C19*].)

In general, single bond linkages between C and C, N, or O will have a frequency of about 800 cm^{-1} (12.5 μ).

Among the organic compounds containing only single-bond (C—C) attachment about a functional group of interest are optical antipodes. Inasmuch as the two isomeric forms of optical antipodes have the same energy content it would not be expected that they would have different absorption, especially since they involve the same types of linkages, and this has been demonstrated by experiment (*C31*) (Fig. 8.22).



Ethylene has an absorption band in the extreme ultraviolet with a frequency of about 1600 f (195 mμ), and as a simple symmetrical unsaturated compound its absorption band is reasonably symmetrical (*C58*) (Fig. 8.24). Homologs of ethylene which are unsymmetrical show a distinct broadening of the band as would be expected. Careful mathematical studies have been made of the resonating systems involved in simple ethenylenic compounds although spectral studies are difficult to make on account of the region of the spectrum involved.

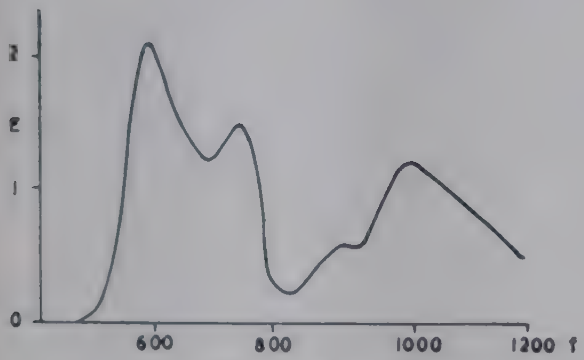


FIG. 8.22

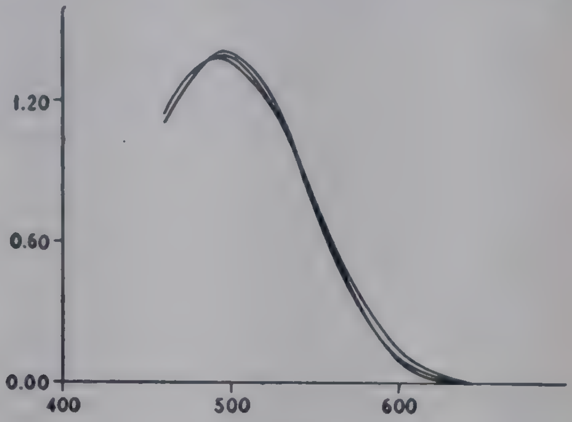
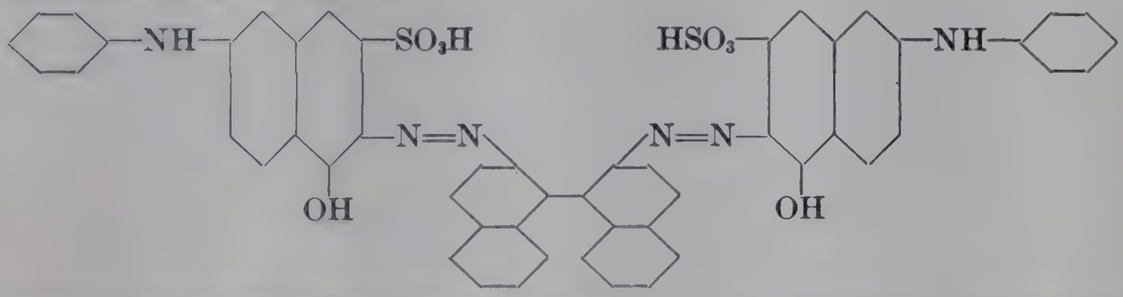


FIG. 8.23

FIG. 8.22. Absorption spectrum of *dl*-phenyl-(*p*-dimethylaminobenzeneazobenzoylamino)-acetic acid in alcohol. $C = 0.0125$ gram per liter; $d = 1$ cm. The absorption spectra curves of the *d* and *l* forms were also determined and found to be identical within the allowable experimental error. (Brode and Adams [*C31*].)

FIG. 8.23. Absorption spectra of *d*-, *l*-, and *dl*-2,2′-bis(6-anilino-1-hydroxy-3-sulfo-2-naphthylazo)-1,1′-binaphthyl.



(Involving molecular rather than atomic asymmetry.) Curves are identical within experimental error. (Brode and Brooks [*C34*].)

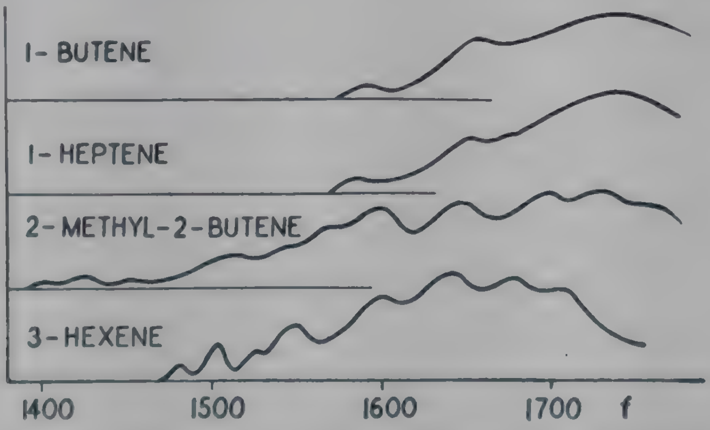
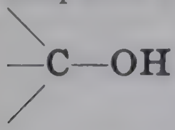


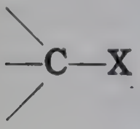
FIG. 8.24. Absorption spectra of olefins (Carr [*C58*]).

—C≡C— Acetylene does not show any marked increase in absorption or any marked change in position of the absorption band (188–215 mμ) as compared with ethylene, which confirms the chemical evidence that acetylene does not exhibit an appreciably greater activity or unsaturation than is shown by ethylene. Acetylene shows only a slight increase in absorption frequency over that of ethylene (2100 cm^{-1}) (188–215 mμ).



The C—OH linkage exhibits only a slightly greater resonance than the C—C linkage, and, as might be expected, the simple alcohols in a pure condition are transparent up to the limit of the normal photographic plate (200 mμ). They are therefore quite suitable as solvents for spectrophotometry within this region.

Note. Although alcohols are indicated as possessing little absorption, due care should be taken in the use of alcohol as a solvent to insure purity. Absolute ethyl alcohol often contains benzene, which makes it unfit as a solvent for ultraviolet absorption spectrophotometry.



Ethyl iodide shows a single band at 250 mμ which is not appreciably changed by alteration of the solvent from carbontetrachloride to hexane to ethyl alcohol although its extinction is reduced by the use of water as a solvent. Iodoform (CHI_3) shows absorption bands at 348, 307, and 275 mμ, and a fourth is indicated in the extreme ultraviolet. In the cases of the simple C—Cl and C—Br linkage there is very little absorption within the spectrum down to 200 mμ.

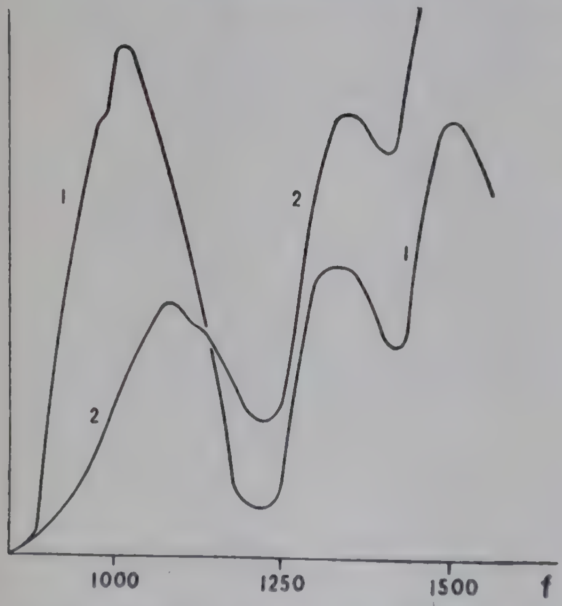


Fig. 8.25. Absorption spectra of trans (1) and cis (2) stilbene in ethyl alcohol (Smakula and Wassermann [*C185*]).

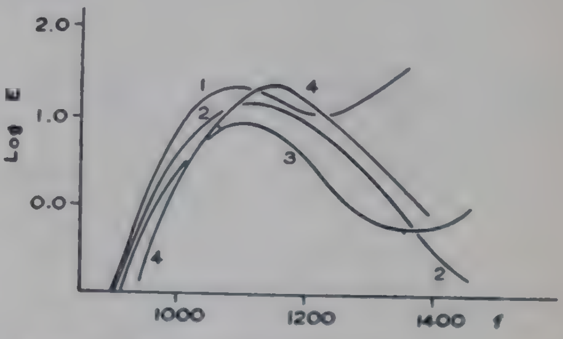
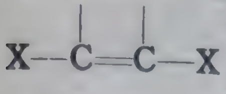
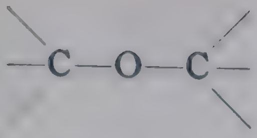


Fig. 8.26. Absorption spectra of propylethyl ketone (1), acetone in alcohol (2), acetaldehyde (3), and acetone in hexane (4).

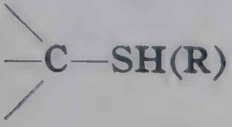


$X—\overset{|}{C}=\overset{|}{C}—X$

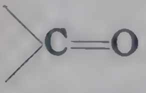
The combination of halogens and ethylene resonating systems presents an interesting study on account of the different energy values of the cis and trans forms. The cis forms, as might be expected from their lower stability, have slightly greater absorbing properties than the trans forms (Fig. 8.25).



Ethers possess the property of coordination and, as such, might be expected to show some absorption, but in their noncoordinated form, especially if the —O— linkage is buried well within the molecule, it has much the same resonating property as a $—CH_2—$ linkage. This property of the oxygen linkage to act as a nontransmitter of resonance or a shock-absorber is well demonstrated in the failure of the change of the R group in $R—O—C_6H_5—N=N—C_6H_5OH$ to alter appreciably the nature of the absorption spectra of the resonating chromophore.



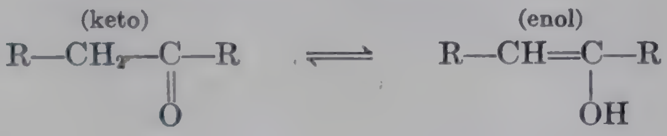
Similar studies on the change of color of thiophenolic compounds indicate that sulfur is also a resonating insulator.



The ultraviolet absorption spectrum of acetone (Fig. 8.26) shows a strong absorption band at 1110 f (270.6 mμ) in an alcohol solution. The increase in size of the alkyl radicals in the ketone produces a slight increase in the extinction coefficient and a slight reduction in the frequency of the absorption band. Acetaldehyde shows absorption at about the same frequency as the acetone band, but at a somewhat lower extinction coefficient. In a nonpolarizing solvent, such as hexane, the carbonyl band shows an increase in extinction (*C130*).

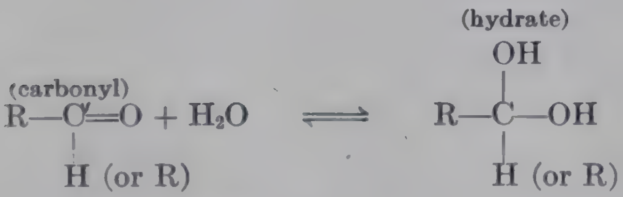
In addition to this hyperchromic and hypsochromic effect due to a change in hydrocarbon content of the alkyl radicals attached to the carbonyl, an even greater effect is produced on the carbonyl absorption band as a result of a tautomeric equilibrium between enol and keto forms (*a*), and in the complete elimination of the unsaturated condition in the molecule through hydration or a similar reaction (*b*).

(*a*)



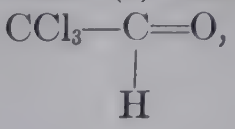
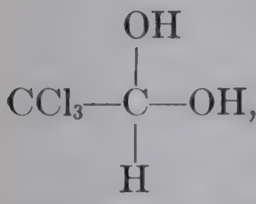
$$\underset{\text{(keto)}}{R—CH_2—\underset{\underset{O}{\|}}{C}—R} \rightleftharpoons \underset{\text{(enol)}}{R—CH=\underset{\underset{OH}{|}}{C}—R}$$

(*b*)



$$\underset{\text{(carbonyl)}}{R—\underset{\underset{\text{H (or R)}}{|}}{C}=O} + H_2O \rightleftharpoons \underset{\text{(hydrate)}}{R—\overset{\overset{OH}{|}}{\underset{\underset{\text{H (or R)}}{|}}{C}}—OH}$$

The tautomeric equilibrium effect (*a*) is easily demonstrated in the 1,3-diketo compounds, such as acetoacetic ester and acetylacetone (see the discussion in this chapter on conjugated chromophores). The reduction, by the addition of alkali, of the extinction coefficient of the absorption band produced by acetone and other carbonyl compounds is explained on the formation of a salt with the hydroxyl hydrogen of the enol form.

With regard to the hydration effect (*b*) the difference between the absorption spectra of chloral,  $\mathrm{CCl_3{-}\underset{\displaystyle H}{\underset{|}{C}}{=}O}$, and chloral hydrate,  $\mathrm{CCl_3{-}\overset{\displaystyle OH}{\overset{|}{\underset{\underset{\displaystyle H}{|}}{C}}}{-}OH}$, and the failure of formaldehyde, which shows a marked absorption in the vapor state (Fig. 8.1) and in hexane solution, to show appreciable absorption in an aqueous solution (Fig. 8.27) are sufficient to demonstrate this structural change.

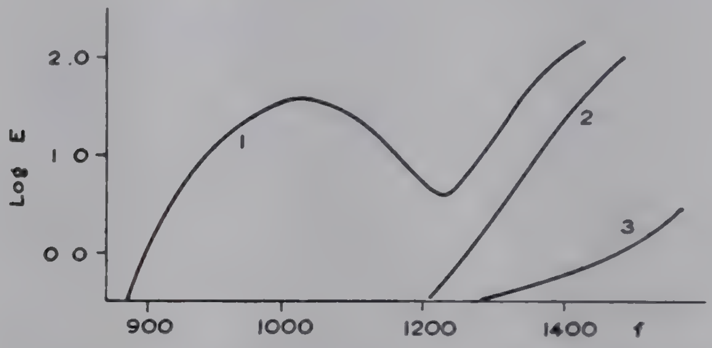
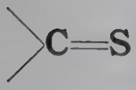
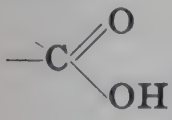


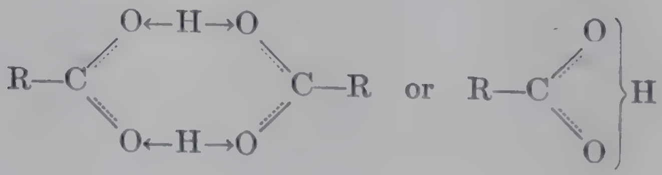
FIG. 8.27. Absorption spectra of (1) chloral in hexane; (2) chloral hydrate in water; (3) formaldehyde in water (Schou [*C108*]).



The increased mass and resonating property of the sulfur atom as compared with the oxygen atom will naturally give rise to a bathochromic and hyperchromic effect with an increase in absorption and a shift of the band to lower frequency (*C130*). The change from oxygen to sulfur in colorless benzophenone yields a blue thiobenzophenone.



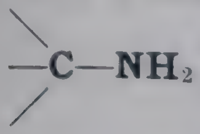
Acids, in a similar manner to formaldehyde, undergo, in water, association and hydrolysis with a loss of their carbonyl structure:



The hydroxyl group apparently inhibits the resonance or existence of the carbonyl group, and most of the simple aliphatic acids are transparent down to 220 or 230 mμ. The presence of a carboxyl group in a molecule does, however, affect the resonance of other groups in the molecule even though it is not conjugated or in juxtaposition to the other resonating group.

—COOR Esters, like their parent components, alcohols and acids, show only slight absorption, and that in the extreme ultraviolet.

—$CONH_2$ The combination of other groups such as NH_2 to the carboxyl to form an amide fails to alter appreciably the absorption spectra of the compound.


$>C-NH_2$

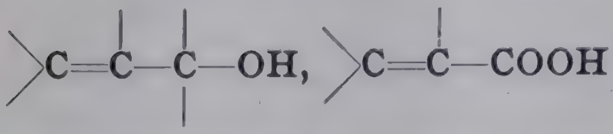
As might be predicted from the similar properties of water and ammonia, amines will tend to show more absorption than alcohols. The slight increase in resonance is sufficient, however, to bring the absorption band just within the photographic range. The absorption of amines is reduced as one goes from the pure compound to solutions of hexane, alcohol, water, and, lastly, acids (salt formation) in which the solution is completely transparent within the photographic range.

NH_2—ACIDS Combinations of acids with amines within the same molecule, such as the alpha-amino acids, usually result in inner salts, and hence we may expect protein material to show little absorption except for aromatic or other resonating groups which are present. The same may be said with regard to the hydroxy acids (**OH—)ACIDS**. Polyhydroxy aldehydes (**OH—ALDEHYDES**), which are the principal constituent groups of the carbohydrates, will show absorption only when a free carbonyl group or unsaturated linkage is present.

—NO_2, —NO_3 The nitro, nitrite, nitroso, nitrosamine, and nitrate derivatives of organic compounds all show absorption which is due to the —N=O group, a powerful resonator producing bands in the near ultraviolet and visible region of the spectrum. Nitrobenzene has a very intense band at 294 mμ which starts in the visible as evidenced by its natural yellow color. Nitro and nitroso compounds, especially the latter, are extremely powerful chromogens, e.g., nitroso tertiary butane, $(CH_3)_3C—NO$, is a brilliant blue compound, and nitrosobenzene, $C_6H_5—NO$, a green compound.

—N=N— With aliphatic radicals such as the compound $CH_3—N=N—CH_3$ a weak absorption band is shown at 345 mμ, but introduction of resonating phenyl groups at each end results in a compound ($C_6H_5—N=N—C_6H_5$) which absorbs strongly at 445 mμ (Fig. 7.2) and further addition of auxochromic groups (OH, NH_2, etc.) results in brilliant visible color (Fig. 7.55). Introduction of an —NH— or CH_2 group between the —N=N— and a phenyl will shift the band to the ultraviolet.

Conjugated and Adjacent Chromophores



Allyl alcohol, $CH_2{=}CH{-}CH_2OH$, shows a weak band in the photographic region at 234 mμ and a strong band at 193 mμ, indicating a slight conjugation. This is in line with the increased chemical activity of both the C=C and OH resonators. Crotonic acid, $CH_3{-}CH{=}CH{-}COOH$, with a carboxyl group conjugated with the ethenylene group, also shows a marked increase in extinction and a slight shift of the unsaturated ethylenic absorption band towards higher wavelength (lower frequency) values. As one moves the double bond out of conjugation with the COOH there is a marked drop in the extinction, and the compound reverts to what might be considered a simple mixture of the component resonators:

		ϵ
Allyl acetic acid	$CH_2{=}CH{-}CH_2{-}COOH$	19.8
Crotonic acid	$CH_3{-}CH{=}CH{-}COOH$	700

The conjugation of ethenylene linkages with the carboxyl results in a marked increase in extinction as well as a shift of the band to lower fre-

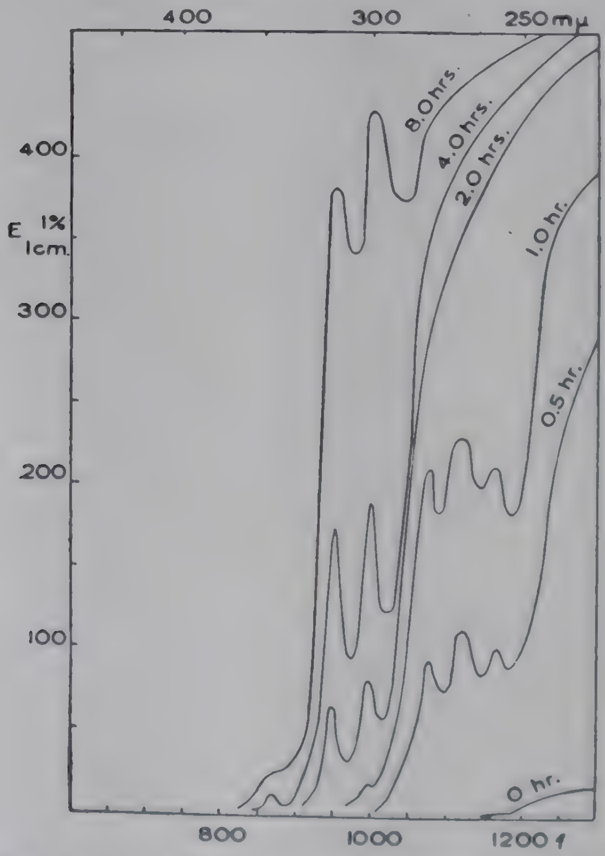


FIG. 8.28. Absorption spectra in isomerized unsaturated acids: Curves indicate absorption spectra of the unsaturated acid heated with alkali for the indicated time. (Brode, Brown, and Mowry [*C48*].)

quency values (Figs. 8.14 and 8.15). If conjugated ethenylene linkages are present in an acid but not conjugated with the carboxyl group, such as are produced on the isomerization of linoleic acid (Fig. 8.28) and higher members of the unsaturated fatty acid series, there are produced sharp, well-defined bands similar to the conjugated unsaturated hydrocarbons (Fig. 8.15).

A highly unsaturated acid such as arachiodnic acid has the formula $CH_3—(CH_2)_4—CH{=}CH—CH_2—CH{=}CH—CH_2—CH{=}CH—CH_2—CH{=}CH—(CH_2)_3—COOH$, in which none of the unsaturated linkages are conjugated. The absorption spectrum of this acid shows no sharp absorption above a frequency of 1100 f. Heating arachiodnic acid with alkali results in isomerization of the acid with a shift of the bonds to conjugated positions. The conjugated acids produced show marked absorption (Fig. 8.28), and it has been possible to isolate and purify the end isomerized product (Fig. 8.29) with four conjugated double bonds.

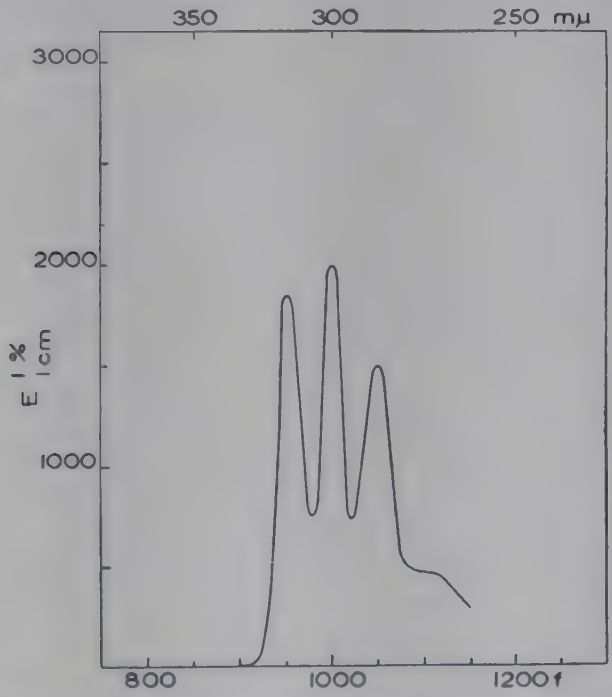
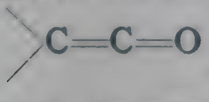
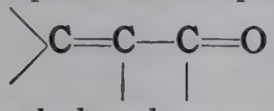


FIG. 8.29. Absorption spectrum of isomerized arachidonic acid with four conjugated double bonds. (Brode, Brown and Mowry [*C48*].)

The combination of an ethenylene and carbonyl group, as might be predicted from the strong absorption of the separate groups, results in marked intensification of absorption and a bathochromic effect in the shift of the absorption band to a lower frequency (Fig. 8.30).


The shared rather than conjugated combination of ethylene and a carbonyl group yields a resonating system which, in part, is dampened by the close proximity of the resonating

parts, and in part is converted into a new triatomic resonator yielding different bands from the original component groups. Ketene, $CH_2{=}C{=}O$, exhibits two bands at 324.4 mμ and at 267.1 mμ, and a third, indicated at about 230 mμ. Diethyl ketene shows absorption bands at 373.5 and 224.1 mμ. In both, the band in the neighborhood of 230 mμ is very intense as compared with the band at the longer-wavelength position. In the vapor state ketene shows a fine structure system, such as formaldehyde shows, and at about the same position as the solution bands of the compound. There is little doubt but that the close coupling of the two resonating groups in ketene has resulted in the formation of a new coupled chromophore or resonating system.



$>C{=}\underset{|}{C}{-}\underset{|}{C}{=}O$

The combination of an ethylene and carbonyl resonator in a conjugated coupling (alternate double- and single-bond arrangement) results in hyperchromic and bathochromic effects (intensification and shift to lower frequency values) which are almost equivalent to a new resonating system involving the two units

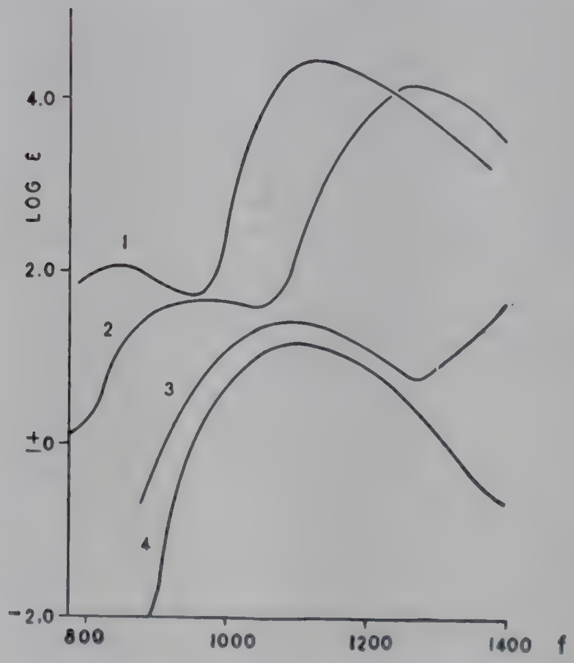
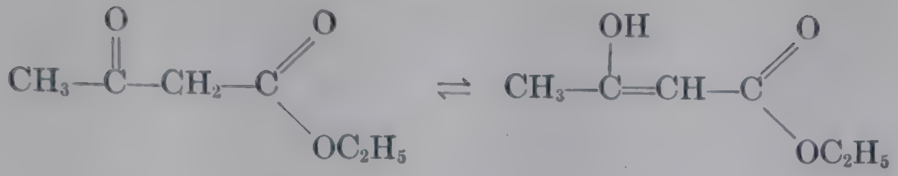
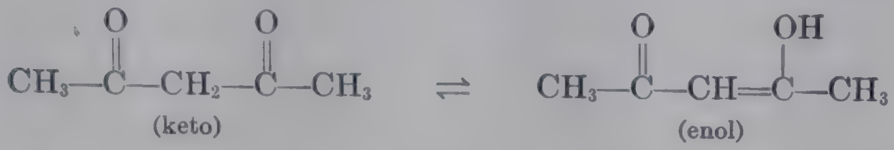


FIG. 8.30. Absorption spectra of (1) phorone, $CH_3{-}\underset{CH_3}{\underset{|}{C}}{=}CH{-}\underset{O}{\underset{\|}{C}}{-}CH{=}\underset{CH_3}{\underset{|}{C}}{-}CH_3$; (2) mesityloxide, $CH_3{-}\underset{CH_3}{\underset{|}{C}}{=}CH{-}\underset{O}{\underset{\|}{C}}{-}CH_3$; (3) allylacetone, $CH_2{=}CH{-}CH_2{-}CO{-}CH_3$; (4) acetone, $CH_3{-}CO{-}CH_3$. (Ley-Henri-Scheibe [*B29*].)

together as the single resonator (Fig. 8.30). Some of our best examples of such compounds are to be found in the derivatives of acetoacetic ester (*a*) and the 1,3-diketones (*b*) in their enol forms.

(a) 

$$CH_3-\overset{\overset{O}{\|}}{C}-CH_2-C{\overset{O}{\diagup\!\!\diagup}}\backslash OC_2H_5 \rightleftharpoons CH_3-\overset{\overset{OH}{|}}{C}=CH-C{\overset{O}{\diagup\!\!\diagup}}\backslash OC_2H_5$$

(b) 

$$\underset{\text{(keto)}}{CH_3-\overset{\overset{O}{\|}}{C}-CH_2-\overset{\overset{O}{\|}}{C}-CH_3} \rightleftharpoons \underset{\text{(enol)}}{CH_3-\overset{\overset{O}{\|}}{C}-CH=\overset{\overset{OH}{|}}{C}-CH_3}$$

In the equilibrium between the enol and keto forms the enol form possesses a C=C—C=O structure which provides a means of determining the amount of enol form in this equilibrium through the absorption spectrum of the solution. A comparison of the absorption spectra of a series of such compounds will illustrate the application of this method and the effect of certain solvents in inducing or repressing the equilibrium toward the enol form.

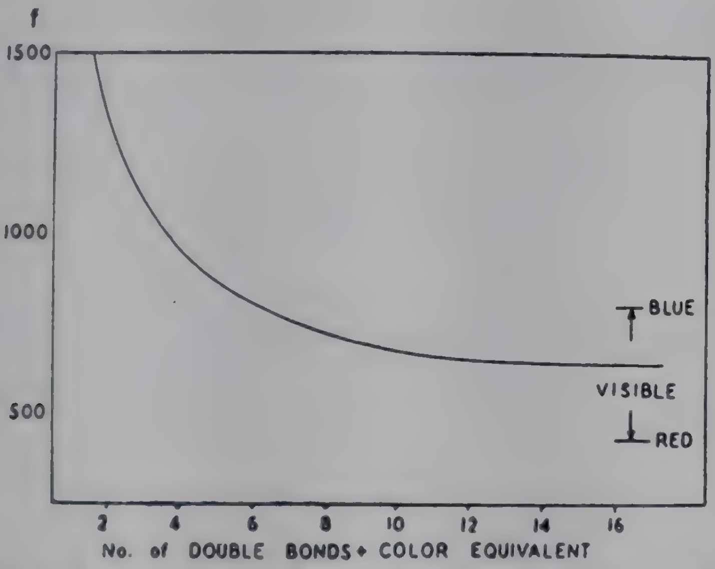
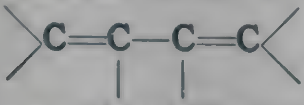
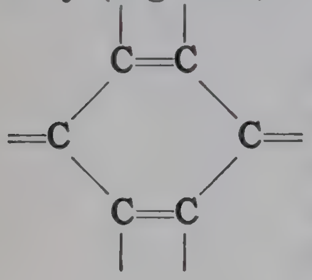


Fig. 8.31. Shift of absorption band with increase in number of double bonds in $C_6H_5-(CH=CH)_n-C_6H_5$ (Hausser). See Fig. 8.15 for examples of the absorption spectra of compounds indicated (*C103*).

Conjugation of C=C to C=O gives spectra similar in intensity and position to the absorption spectra of polyenes having the same number of conjugated bonds, thus indicating that the transition process must be similar in the two systems (*C130*).

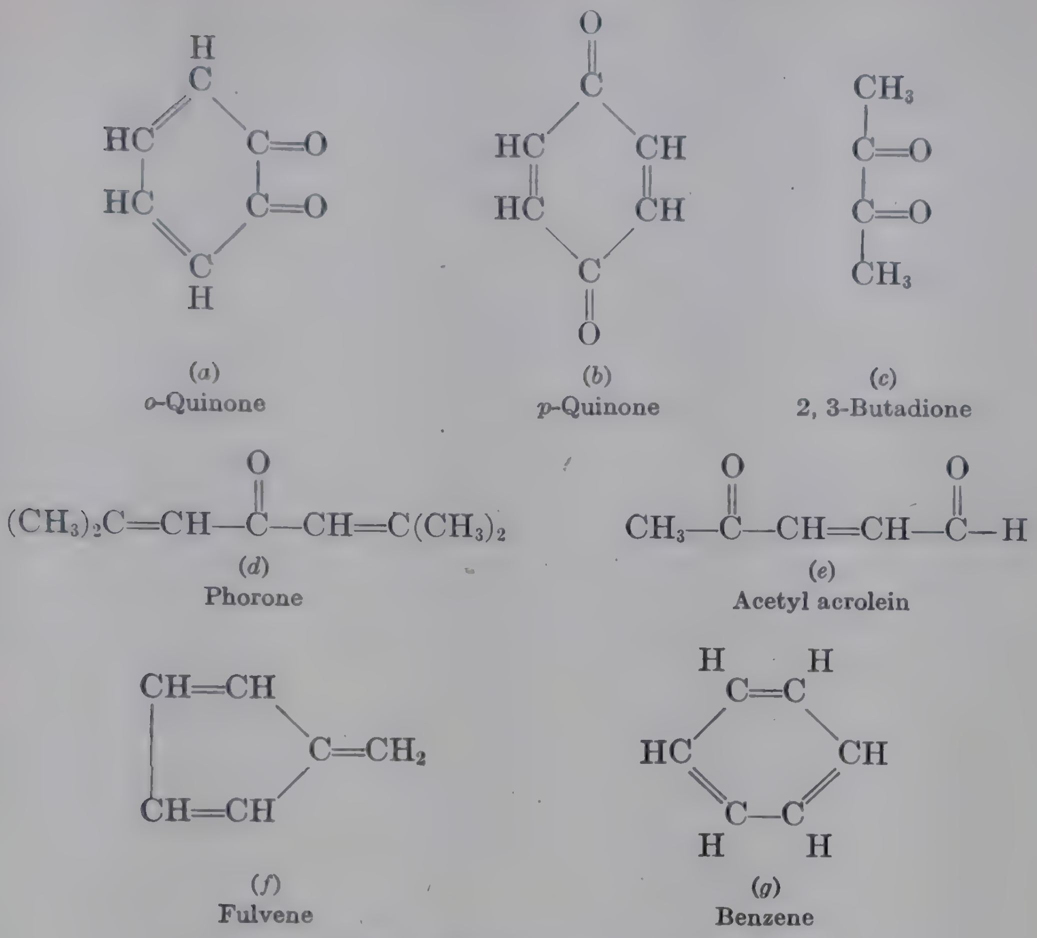


$>\underset{|}{C}=C-\underset{|}{C}=C<$ Conjugated ethenylene linkages, like the conjugated ethenylene-carbonyl grouping, result in interresonance, the shift of the band toward the visible from the ultraviolet, and marked increase in intensity. Hausser has examined the unsaturated acid and diphenyl derivatives with conjugated double bonds, and his series of curves give a very good illustration of the effect (Fig. 8.31). As the number of conjugated linkages is increased, the rate of shift of the frequency and intensity of the band decreases so that the possible shift of the band is subject to a limiting condition. This limit of shift, together with the decrease of stability, is one of the important factors which prevents the easy extension of the range of sensitization of photographic plates for the infrared. Brooker and Hamer have shown (Figs. 9.30 and 9.31) (*C56*, *C81*) that as one increases the number of conjugated ethenylene linkages between two resonating groups in the cyanine type of dye there is a shift of sensitization property toward lower frequency which is concomitant with the shift in absorption center and decrease in stability of the dye. Modifications which may be incorporated into the dye structure and which may improve the stability include such effects as weighting of the long conjugated chain at some point between the two end resonators. In general the introduction of ethenylene groups between two resonators is of an auxochromic nature in that the band is given a bathochromic shift and an increase in intensity (Fig. 9.27).



Quinones The *ortho* and *para* quinones are special cases of the combination of several resonating carbonyl and ethenylene groups. In view of the large number of possible resonating systems which may be postulated in these compounds and the fact that some are conjugated and some are adjacent it becomes extremely difficult to assign to any one particular group the specific absorption effect observed in a given portion of the spectrum. It is more apparent that the combination or grouping of resonators can be considered a unit system of resonance or vibration. It is possible to make some comparison between such structures as 2,3-butadione (*c*) and *o*-quinone (*a*). Similar comparisons can be made between phorone (*d*), *p*-quinone (*b*), acetyl acrolein (*e*), and fulvene (*f*), (Fig. 8.32). With the increase in resonance properties of a molecule there is a corresponding shift toward the visible from the ultraviolet, and an increase in intensity, together with a resolution effect. The band becomes resolvable, in many cases, into structural components which have an approximate constant frequency separation, and the observed frequency of the absorption band component is an integral multiple of this constant frequency difference. This apparent simplification of the absorption band structure as one increases the resonance complexity of the molecule lends support to the theory that the more complicated molecular absorbing units may act as a single resonator and, because of their size, respond more like a simple harmonic vibrating system.

Benzene and Aromatic Compounds. The conjugation of ethenylene



(a) o-Quinone

(b) p-Quinone

(c) 2, 3-Butadione

(d) Phorone

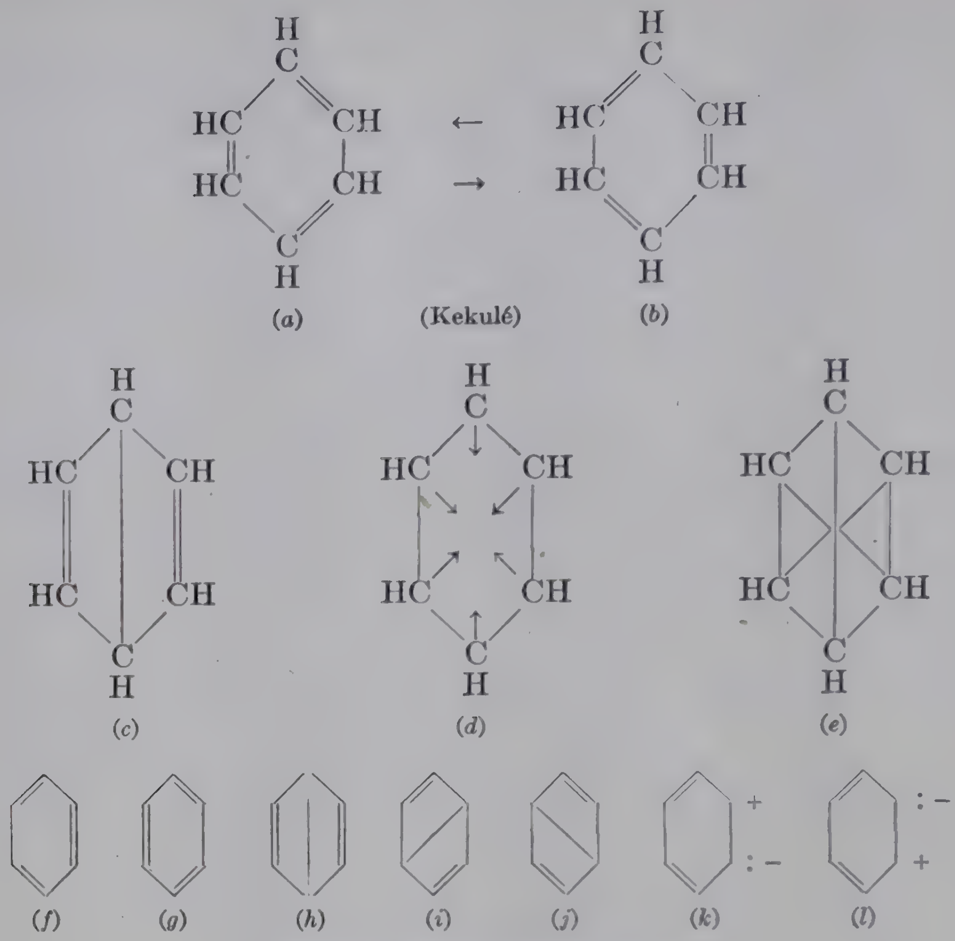
(e) Acetyl acrolein

(f) Fulvene

(g) Benzene

Fig. 8.32. Conjugated Resonators

linkages results in a decrease in chemical activity and an increase in stability of the unsaturated linkages in the middle of the conjugated chain, and an increased activity of the end groups in the conjugated chain. Benzene, because of its unusual structure, may be considered an endless conjugated chain, in that the bonds continue in conjugation as one goes around the ring. One may further postulate a resonating system for benzene as oscillation between the two Kekulé formulas (Fig. 8.33 *a* and *b*). Many other formulas have been proposed for benzene, such as the Dewar (bridged) formula (*c*), the Armstrong-Baeyer formula (*d*), and the Claus formula (*e*). Whatever formula is accepted, however, it must permit of marked stability and resonance. Pauling (*B63*) has indicated that the resonating formulas can best be explained by the forms *f g h i j*, in which the major resonating system is represented by *f* and *g*. Benzene is in itself a very symmetrical molecule, and as such we would expect it to have a very symmetrical and well-defined absorption spectrum. In the vapor state, benzene exhibits a band spectrum (Fig. 8.34) with a remarkable resolution of the band components. As can be seen from Table 8.3, the bands appear to be multiples of a band which is known to exist in the infrared at a frequency value of 30.2 f (1006 cm^{-1}).



Resonating Forms (Pauling [*B64*])

Fig. 8.33. Structural Formulas of Benzene

Several methods of band analysis have been applied, and, as might be expected with a band with well-resolved fine structure and an apparent multiple relation, the systems of analysis have been very successful (Table 8.3) (*C188*).

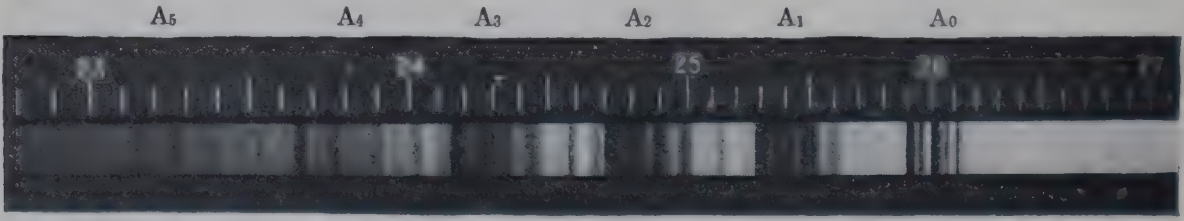
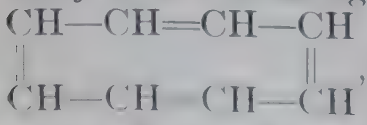


Fig. 8.34. Absorption spectrum of benzene (vapor). P.

The freedom from ring strain in the benzene nucleus as well as its planar structure must have a great deal to do with the marked stability and resonating properties of the ring, since cycloöctatetraene,



$$\begin{array}{l} CH-CH=CH-CH \\ \| \qquad\qquad\qquad\quad \| \\ CH-CH=CH-CH \end{array}$$

, does not have such marked stability or resonating power. Internal or external forces tend to inhibit the resonance of the

TABLE 8.3

ANALYSIS OF THE BENZENE ABSORPTION BAND

Component	Formula				Observed	
	a. (*B28*) $n(1006)$ cm^{-1}		b. (*C188*) $38{,}608 + n(923)$ cm^{-1}			
A_0	$n = 38$	38,300 cm^{-1}	$n = 0$	38,608 cm^{-1}	38,310 cm^{-1}	261 mμ
A_1	39	39,306	1	39,531	39,310	255
A_2	40	40,312	2	40,454	40,320	248
A_3	41	41,318	3	41,377	41,320	242
A_4	42	42,324	4	42,300	42,300	237
A_5	43	43,330	5	43,223	43,300	232

molecule, as is evidenced by the influence in solution of solvents, especially polar solvents, on the benzene absorption spectrum. Internal forces may be described as actual molecular combination with the benzene ring, such as the substitution of methyl, carboxyl, hydroxyl, and similar groups (Fig. 8.35) in which there is practically always a resonance dampening. The fine structure of the benzene absorption is often obliterated by this dampening effect, although the added group may be an auxochrome in character and may markedly increase the absorption as well as shift the band towards the visible.

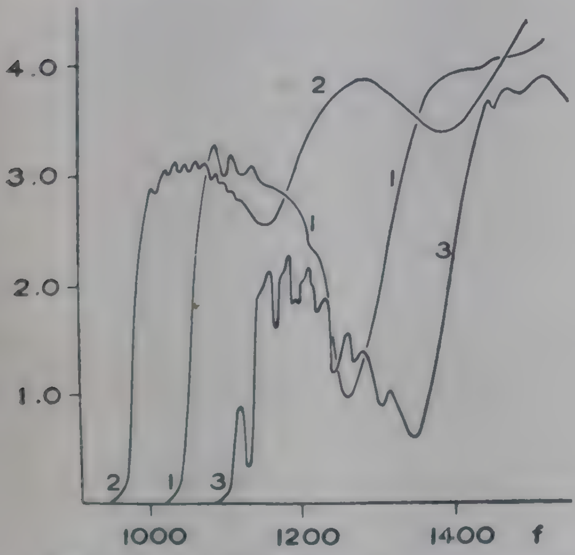


FIG. 8.35. Absorption spectra of benzene and substituted derivatives: 1, phenol; 2, aniline; 3, benzene. (Klingstedt-Brode [*B29*].)

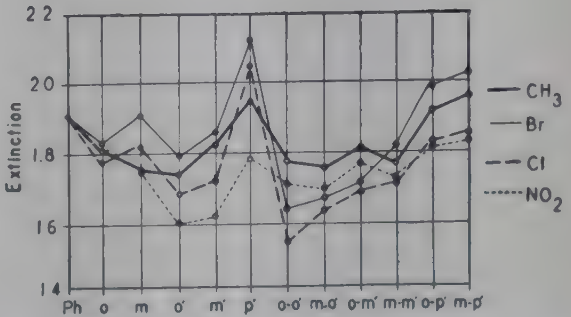


FIG. 8.36. Influence of position of substitution in benzenazophenol on the extinction coefficient of the absorption band (Brode [*C30*]).

The influence of position of substitution by weighing groups is demonstrated by the studies of the author (*C27*, *C38*, *C40*) on the azo dyes. Figures 8.36, 83.7, and 8.38 show that as the position of substitution is varied in either benzene or naphthalene there is a definite effect on the absorption band frequency and extinction. In particular it is to be noted that certain substitutions placed *ortho* to the chromophore create a marked inhibition of the extinction values while substitutions *para* to the chromophore or *ortho* to a *para* substituted auxochrome enhance

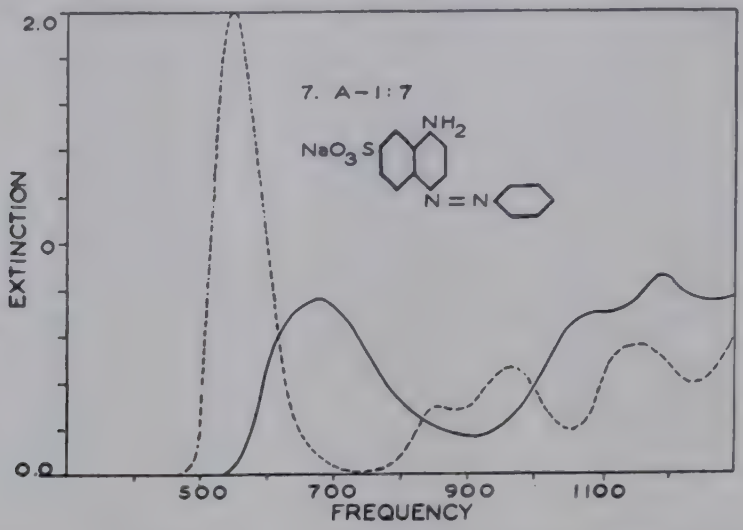


FIG. 8.37. Absorption spectra of a monoazo dye in water (solid line) and HCl (dotted line).

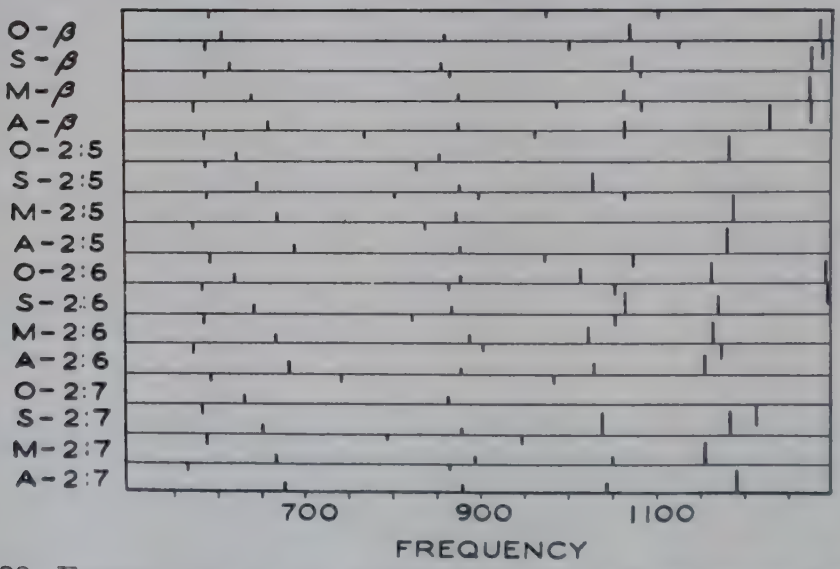


FIG. 8.38. Frequencies of the principal maxima of monoazo dyes prepared by diazotization of aniline (*A*), sulfanilic acid (*S*), metanilic acid (*M*), and orthanilic acid (*O*), and coupling the diazonium salt to beta-naphthol (β) and the corresponding 5-, 6-, and 7-sulfonated derivatives of β-naphthol. The length of the lines indicates relative intensity of the absorption band. Lines pointing upward represent maxima observed in a neutral (water) solvent; lines pointing downward represent maxima observed in an acid (HCl) solvent. (Brode, Griffith, and Eberhart [*C36; C40*].) See Fig. 8.37.

these properties. In certain solvents there appears to be an equilibrium between two forms with slightly different frequency of absorption bands, and this equilibrium is markedly influenced by the position of the substituting group.

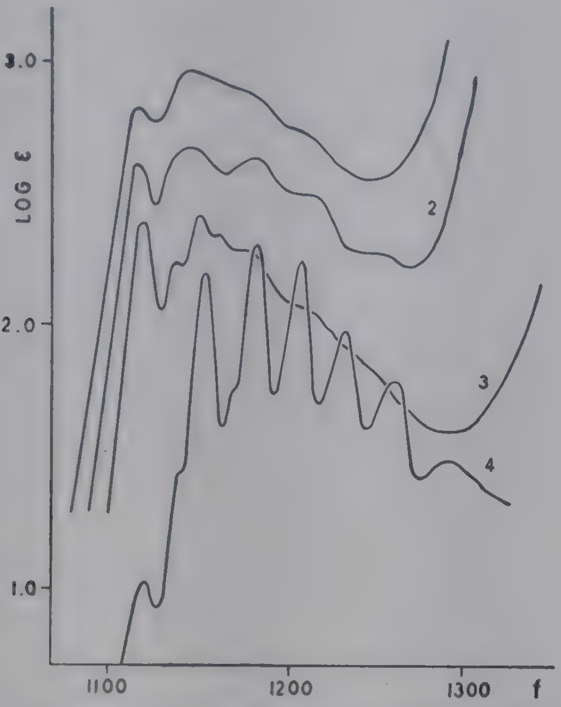


FIG. 8.39. Absorption spectra of polyphenyl compounds: 1, triphenylmethane; 2, diphenylmethane; 3, toluene; 4, benzene (Ley-Orndorff [*C124*]).

As might be expected, the naphthalene and higher aromatic hydrocarbons, which may be considered as resonator substituted benzene compounds, show a shift and intensification of the absorption band but without much loss in the band structure resolution in the vapor and solution states (*C68*) (Figs. 8.39 and 8.40). It is difficult to say which group is to be considered the chromophore and which the auxochrome, when the benzene ring and another resonating group are attached in

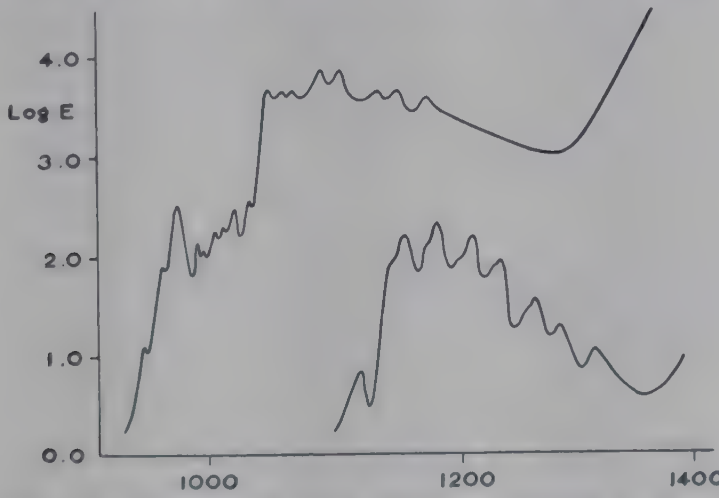


FIG. 8.40. Absorption spectra of naphthalene (upper) and benzene (lower) (de Lasslo-Henri [*C68*]).

alternate position. The marked stability of the benzene resonator and the known fact that chromophoric groups in the center of a chain of conjugated resonators are stabilized by the end resonators makes it possible to prepare fairly stable resonating compounds with benzene rings at each end and resonators in the middle. Similar compounds with aliphatic end groups would normally be unstable. Examples of such aromatic compounds include the azo dyes and triphenylmethane free radicals (Fig. 8.41).

The combination of two or more aromatic rings may take the form of the polycyclic compounds such as naphthalene and anthracene which have been discussed and whose resonance forms have been rather carefully studied (*B63*). A second type of coupling is that of the diphenyl series in which the molecule still acts as a single resonator since the benzene rings are conjugated together. A third type is that in which the

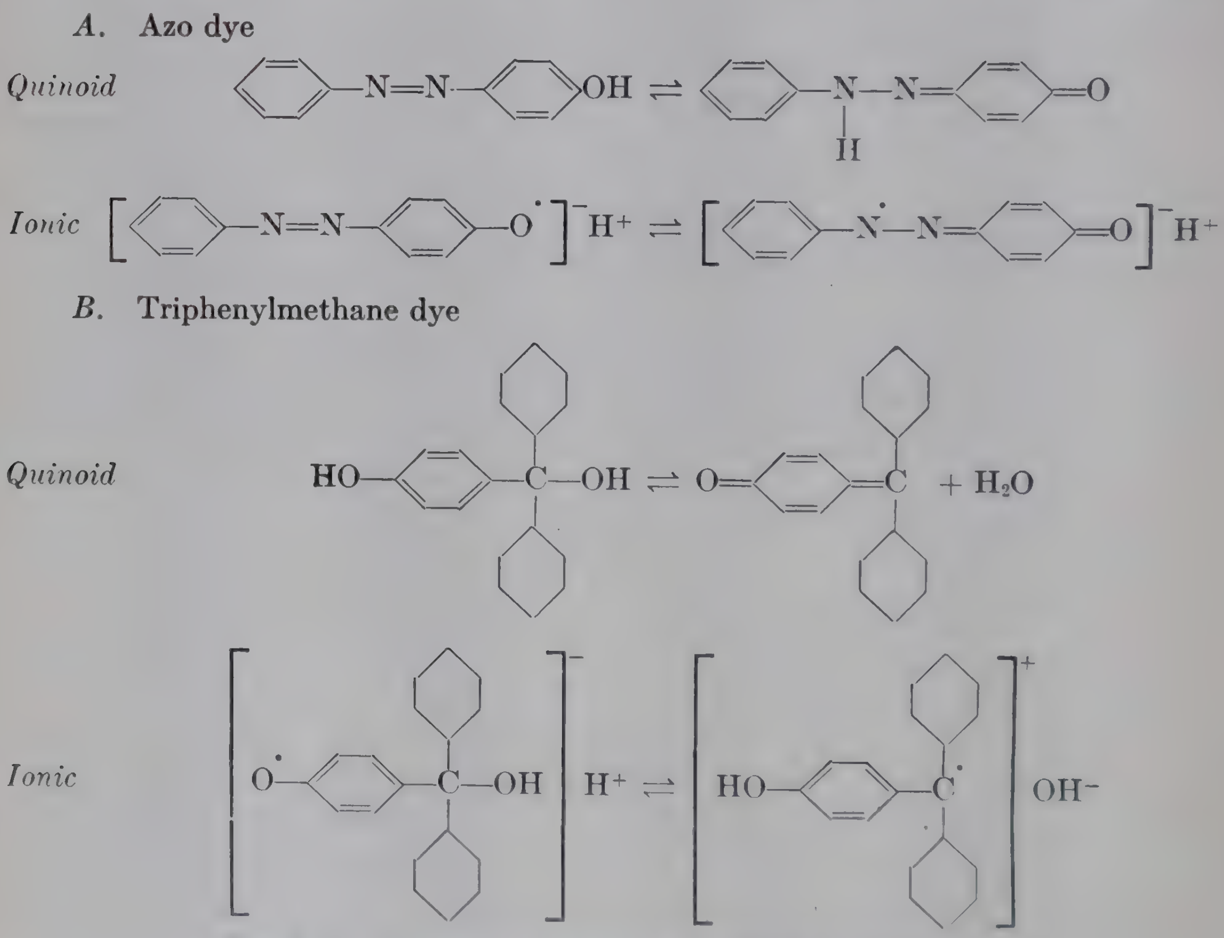
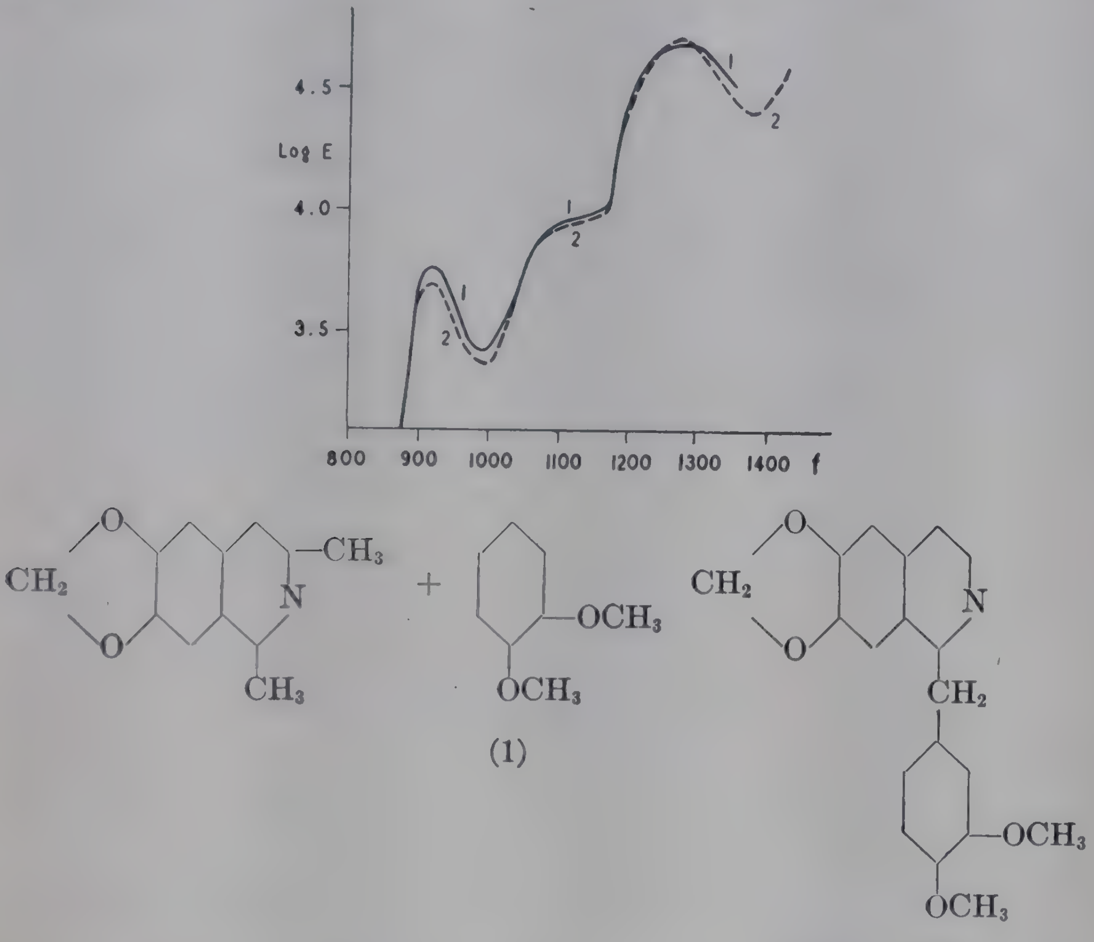


FIG. 8.41. Quinoid and Ionic Resonating Structures

rings are separated by a single carbon linkage, in which event we may expect more or less simple addition of the resonating effects of the separated chromophores (Fig. 8.42), except in so far as the single carbon may be able to transmit resonance effects. This transmission of resonance effects by a single carbon is very slight as can be seen, for example, in the azo dye series (Figs. 8.43 and 8.44). The separation of resonating groups by two methylene (—CH_2—) groups is even more effective in preventing resonance transfer; but the change of the —CH_2—CH_2— to a —CH═CH— group results in the direct coupling together of the resonating groups, and an increase in the number of these —CH═CH— groups between the end resonating systems results in a marked increase in the absorption as well as a shift to lower frequency values.



(2)

Fig. 8.42. Insulating effect of methylene (—CH_2—) linkage between chromophores. Absorption spectra of: (1) veratrol + 1,3-dimethyl-6, 7-methylene dioxyisoquinoline; (2) homoveratryl-3-methyl-6, 7-methylenedioxyisoquinoline. (Gerendas, Varga, and Fordor [*C86*].)

It is thus apparent that the ethenylene linkage produces a single resonator from the two resonating groups by means of its transmitting properties, and at the same time through its chromophoric and auxochromic properties produces a still larger and more powerful resonator.

While it is expected that the simple compounds di- or triphenylmethane will not have conjugated benzene rings, the formation of a chromophore with the methane carbon such as is produced in the di- and triphenylmethane dyes results in two resonating systems, both conjugated to the chromophore. A simpler example of crossed conjugation is found in the fulvene structure with a marked increase in absorption. As was explained in the earlier discussion on resonance and valence it is not necessary to consider that a quinone structure actually forms, but rather that the carbon of the methane portion may be considered as a charged and resonating unit, with which the benzene rings are conjugated.

SUMMARY OF ABSORPTION SPECTRA EFFECTS

The absorption of light by organic and inorganic molecules is due to a resonator or group of resonators. These resonators may be coupled or separated in the molecule; if coupled they may be directly coupled (cumulation), or coupled through a single bond (conjugation). For the most part, resonating atoms or groups of atoms are unsaturated or contain an incomplete inner shell of electrons. To each of these resonating groups may be assigned a certain frequency factor, but it is difficult to predict from these values (Tables 8.2 and 10.1) the absorption bands of a complex molecule unless each resonator is independent and well shielded from the other resonating systems. The close proximity or conjugation of resonators results in bathochromic and hyperchromic effects which are not easily predictable. In addition to these resonators or chromophores there are a number of groups which are known as auxochromes or amplifying groups, which in themselves do not always produce resonance but which have a powerful effect on the resonance of

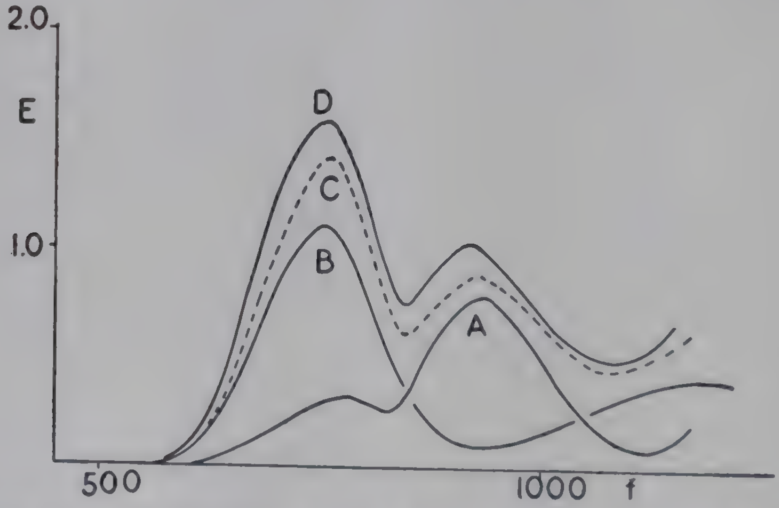


FIG. 8.43. Separated resonators. *A* and *B* are absorption spectra of two monoazo dyes; *C* the addition of these curves; and *D* the absorption spectrum of a disazo dye containing resonators *A* and *B* coupled together by an insulating link. (Brode and Piper [*C50*].)

other systems. These auxochromes may be classed as positive or negative, and their effect varies with the position of attachment of the group to the resonating system.

For complicated resonating structures there seems to be little hope at the present time of complete analysis of the resonating system. The absorption spectrum does, however, act as a fingerprint or identification for very complicated structures, including the quantitative estimation as well as qualitative identification of the substance. The standard method for the determination of the amount of vitamin A in cod-liver oils and extracts is by the extinction coefficient of its absorption spectrum band at 328 mμ (Morton, *B60*). On account of the large number of resonating systems, the possible combinations of these resonators, and the rather broad and diffuse nature of most absorption bands, it becomes almost impossible to classify absorption band systems in accordance with the resonator in anything like the exact order used in the classification of emission spectral lines of elements.

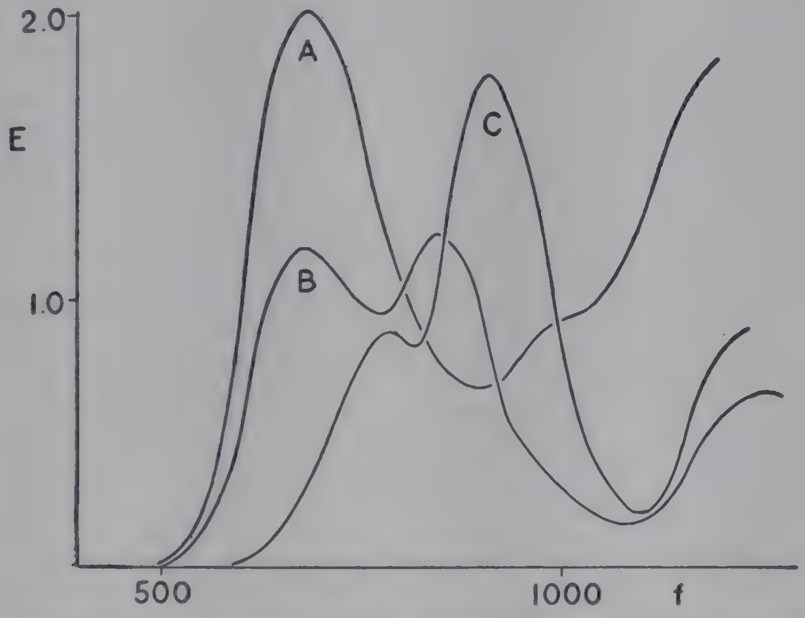


Fig. 8.44. Conjugated and cumulative resonators. Absorption spectra of disazo dyes, (*A*) with the two resonators, (*B*) with the two resonators cumulatively linked and (*C*) with the two resonators separated (Brode and Piper [*C50*]).

Considerable work has been done on the mathematical interpretation of resonance effects, but, like the work in theoretical line spectral analysis, such data cannot be properly or adequately covered in a book on applied spectroscopy. The publications of Branch and Calvin (*B5*), Lewis and Calvin (*C123*), Sklar (*C183*), Mulliken (*C150*), Sponer (*C188*), and others should be consulted for additional data and references in the theoretical aspect of the field. (See Chapter VI, pages 144 to 149.)

LITERATURE

General

R. DE L. KRONIG, "Optical Basis of the Theory of Valence" (*A60*).
H. LEY, "Beziehungen zwischen Absorption und chemischer Konstitution" (*B47*).
G. SCHEIBE and W. FROMEL, "Molekulspektren von Lösungen und Flüssigkeiten" (*B70*).
E. S. MILLER, "Quantitative Biological Spectroscopy" (*B57*).

Reference

WATSON (*B77*), MARTINET (*B55*), HEINRICH (*B30*), COHEN (*B10*), RAMART-LUCAS (*B67*), BRODE and LEERMAKERS (*B8*), GLASSTONE (*A31*), WIZINGER (*B79*), GLASSTONE (*A32*).

CHAPTER IX

APPLICATION OF ABSORPTION SPECTRA DATA

COLLECTIONS OF DATA

It is not possible, in the space available, to go into any detailed discussion of the application of spectrophotometric methods to studies on the determination of structure, biochemical problems, and industrial applications that can utilize spectrophotometric methods. In contrast to developments in the field of emission analysis, the possibility of the application of quantitative methods in absorption spectra analysis was recognized at a very early date, as is evidenced by the publication of a book by Kruss (*B39*) in 1890 (revised edition 1909) on quantitative spectroscopic analysis, dealing with quantitative absorption spectra methods. The nature of absorption bands, however, prevents the detailed analysis that is possible in emission spectra, and hence we have no good compilation or method of classification of absorption spectra such as we have in the Kayser, Harrison, and other emission tables. The number of elements available has a finite limit, but apparently an unlimited number of absorbing resonators is available in organic and inorganic molecules, so that an altogether different problem is faced in the classification and cataloging of absorption spectra data.

Several collected lists of organic and inorganic compounds, whose absorption spectra have been recorded, have been prepared. The usual classification has been alphabetical, although in some lists the compounds have been arranged according to chemical nature. In many of the compilations curves or band positions and extinction values have been included. Among such collections are the following:

1. BALY, E. C. C., STEWART, A. W., and others, a list of compounds whose absorption spectra have been studied, covering work up to 1927. *Proceedings of the British Association for the Advancement of Science* (*C7*).
2. BECQUEREL, J., and ROSSIGNOL, J., "Spectral Absorption of Light and Heat by Pure Inorganic Substances and Miscellaneous Material (Nonmetals)" (in "International Critical Tables," Vol. V, p. 268) (1929) (*B2*).
3. BRODE, W. R., "Recent Applications of Absorption Spectrophotometry," with a supplementary revision covering a selected list of references up to 1932 (*B7*).

4. Carr, E. P., and Sherrill, M. L., "Bibliography of Absorption Spectra of Solutions" (in "International Critical Tables," Vol. V, p. 326) (1929) (*B9*). A list of about 3000 organic compounds and about 300 inorganic compounds, arranged by molecular formula, with literature references to absorption data.

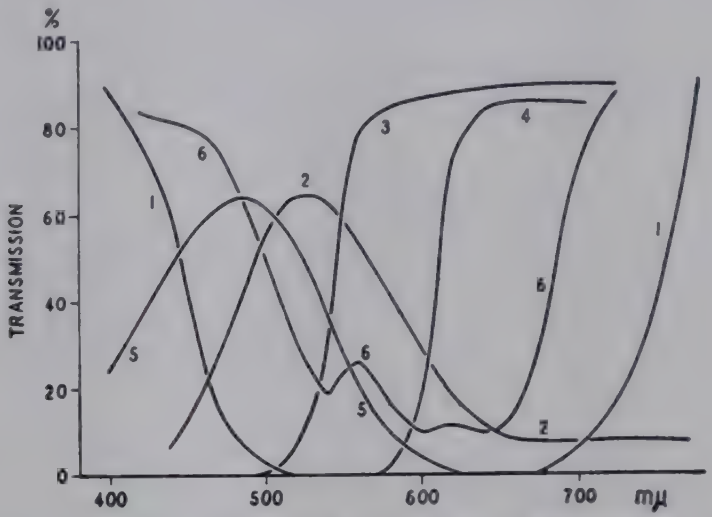


Fig. 9.1. Transmission spectra of glass filters. 1. Jena BG3. 2. Jena VG2. 3. Corning 351. 4. Corning 245. 5. Corning 440. 6. Corning 557. (Gibson (*B22*).

5. Ellinger, F., "Tabulae Biologicae," Vol. XII (1937), a collection of absorption spectra curves of natural products (proteins, sugars, acids, etc.) (*B15*).
6. Formanek, J., "Qualitative Spektralanalyse anorganischer Körper" and "Untersuchung und Nachweis organischer Farbstoffe auf spektroskopischen Wege" (1900, 1908, and 1926). Qualitative and semiquantitative indication of the absorption spectra of a large number of inorganic and organic compounds with special emphasis on dyestuffs (*B19*).

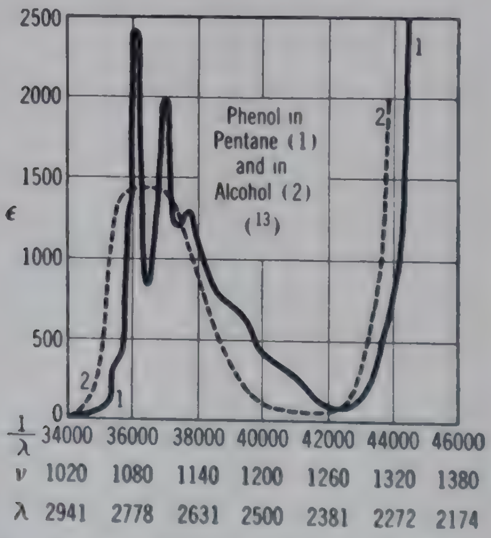


Fig. 9.2. Absorption spectrum of phenol (from data by Henri in Vol. V of the *International Critical Tables*, showing method used in this collection for presentation of absorption data [*B29*]).

7. Gibson, K. S., "Spectral Filters" (in "International Critical Tables," Vol. V, p. 271) (1929) (*B22*). Glass filters. (Fig. 9.1.)

8. **Heyroth, F. F., Ellis, C., and Wells, A. A.**, "The Chemical Action of Ultraviolet Rays." Includes considerable data on absorption spectra of organic compounds (1941) (*B16*).
9. "Handbook of Chemistry and Physics." Transmission and reflection properties of pigments, dyes, glasses, and filters. Tables on pp. 2120–2153, 25th edition (1941) (*A35*).

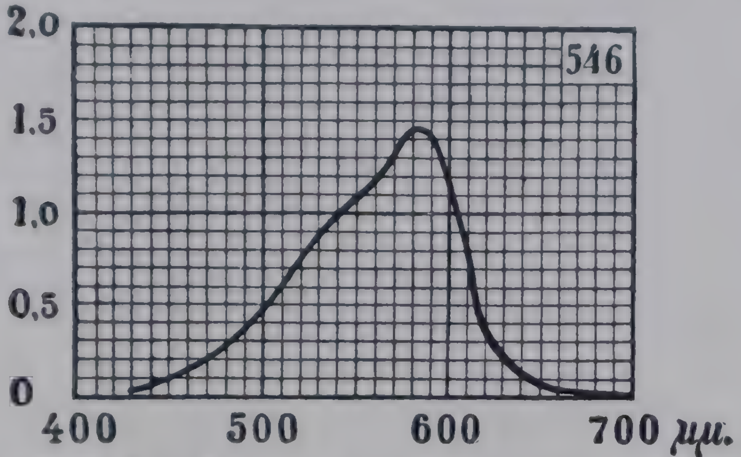


Fig. 9.3. Portion of a page of Lasareff's "Atlas des spectres" (absorption spectrum of methyl violet) (*B40*).

10. **Henri, V.**, "Quantitative Determination of Ultraviolet Absorption Spectra in Solutions of Organic Substances" (in "International Critical Tables," Vol. V, p. 359) (1929) (*B29*). Absorption curves are given on about 150 organic compounds including a number of alkaloids. Data are given in ϵ or log ϵ as ordinates and a combined method of showing λ, ν', and ν in A, cm^{-1}, and f units (Fig. 9.2).
11. **Henri, V., and Bruninghaus, L.**, "*Tables annuelles de constantes et données numériques*, Données numériques de spectroscopie." Volumes I to XII covering work published between 1910 and 1936 give about 750 pages including curves or numerical data obtained from theses and previously unpublished data (*B29*).

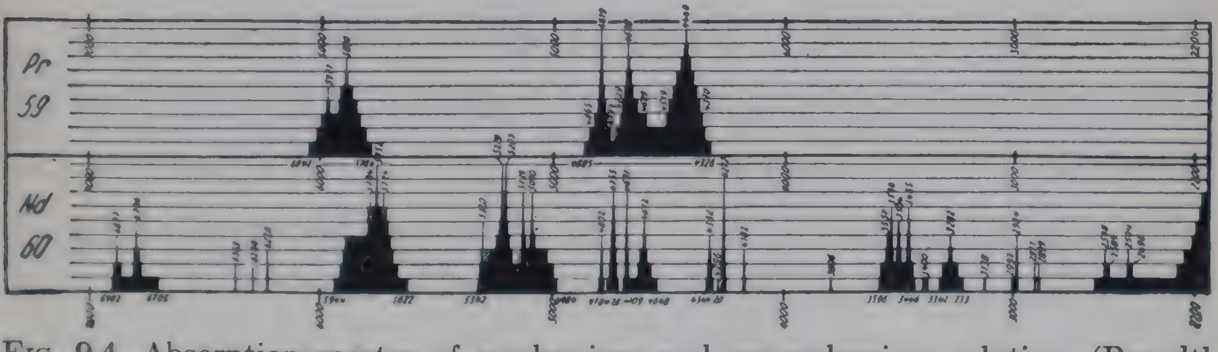


Fig. 9.4. Absorption spectra of neodymium and praseodymium solution (Prandtl and Scheiner [*C165*]).

12. **Holmes, W. C.**, "The Absorption Spectra of Dyes" (in International Critical Tables, Vol. VII, p. 173) (1930) (*B35*). A collection of data and literature references on more than 2000 synthetic organic dyestuffs and several hundred natural pigments. Data include solvents used, position of absorption bands (in mμ) and indication as to relative intensity of the absorption bands. The dyes are classified in the Color Index (*B11*) arrangement, and where possible Color Index numbers are given.

13. Jones, H. C., "The Absorption Spectra of Solutions." Qualitative and semi-quantitative spectrograms of inorganic salts in solution (1909) (*B37*).
14. Landolt-Bornstein, "Physikalische-chemische Tabellen," edited by W. A. Roth and K. Scheel, 5th edition (1923) and three supplementary editions cover the literature up to 1934. These tables include data and curves on organic and inorganic absorption spectra (*A62*).
15. Lasareff, P. P., and Nedopekin, P. M., "Atlas des spectres des substances colorantes." Quantitative visual spectrophotometric measurements on 746 organic dyestuffs, including curves and numerical data (1927) (*B40*). (Fig. 9.3).
16. Mees, E. C. K., "Atlas of Absorption Spectra." Photographic reproductions of wedge spectrograms of important dyestuffs (1909) (*B56*).
17. Miller, E. S., "Quantitative Biological Spectroscopy." A general textbook on absorption spectra procedures with a considerable collection of spectral curves of biological products (1940) (*B57*).
18. Prandtl, W., and Scheiner, K., have given tables and figures on the visible and ultraviolet absorption spectra of the rare-earth salts (Fig. 9.4) (*C165*).

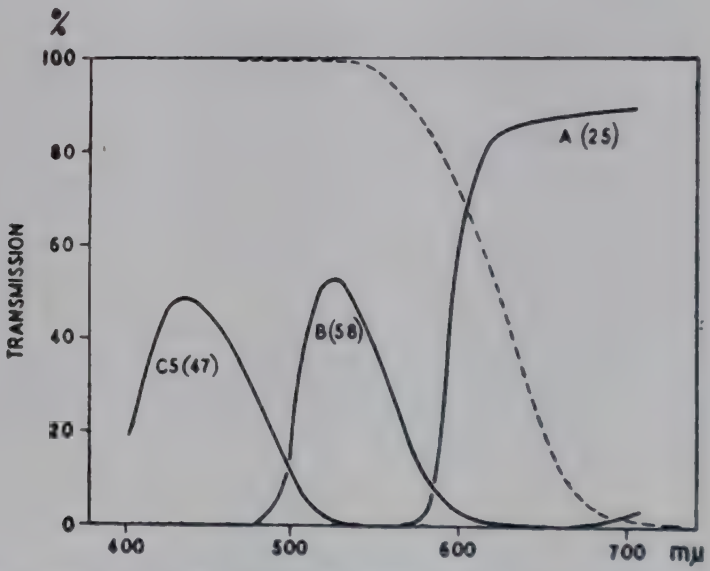


Fig. 9.5. Transmission spectra of gelatin filters for tricolor reproduction. Eastman Blue C5 (No. 47), Green B (No. 58), and Red A (No. 25) (*D12*). Dotted line indicates spectral sensitivity of panchromatic emulsion.

19. "Wratten Light Filters." Data book published by the Eastman Kodak Company, giving absorption data and absorption curves on about one hundred light filters (*D12*) (Fig. 9.5).
20. "Annual Tables of Physical Constants and Numerical Data." (A continuation of the "International Critical Tables" [*A48*]). Edited by N. Thon. Chapters 1 and 2 are to cover data on the spectra and structure of atoms, molecules, solids, and liquids. Data to include material published since 1925 and to be kept up to date with supplementary data compilations (*D18*).

Many organic and inorganic substances, especially when examined in their vapor state, produce band spectra. The following two tables will supply such data and references to further work in this field.

21. Pearse, R. W. B., and Gaydon, A. G., "The Identification of Molecular Spectra." A list of band heads from 2000 to 10,000 A of diatomic molecules and a few triatomic and polyatomic molecules. Includes conversion tables of wavelengths on Rowland's scale to international angstroms and conversion of wavelengths in air to wavelengths in vacuum. A useful table for the identification of band spectra in atomic spectra analysis (1941) (*A77*).
22. Sponer, H., and Teller, E. J., "Electronic Spectra of Polyatomic Molecules." An extensive review of the literature and data on the absorption electronic spectra of polyatomic molecules. Includes a bibliography of 231 references and data on 100 inorganic and 200 organic compounds that have been studied with respect to electronic absorption spectra (1941) (*C188*).

In addition to the above references, which deal specifically with absorption data, the following sources will be found useful where the formula or nature of the compound is known.

23. "Color Index," edited by F. M. Rowe (1924) (*B11*). A collection of data on several thousand dyes of commercial importance. The dyes are arranged in the accepted order of dye classification according to chromophores. Where data are available the position of the absorption bands is given.
24. Schultz, "Farbstofftabellen," edited by L. Lehman (1930–1940) (*B17*). A collection similar to the Color Index with a more complete listing of important commercial dyes. Absorption spectra data are given for some of the dyes.
25. "Beilsteins Handbuch der organische Chemie," 4th edition (1918–1941) (*B3*). A very complete listing of organic compounds and their properties, including references to the absorption spectra of the compound.

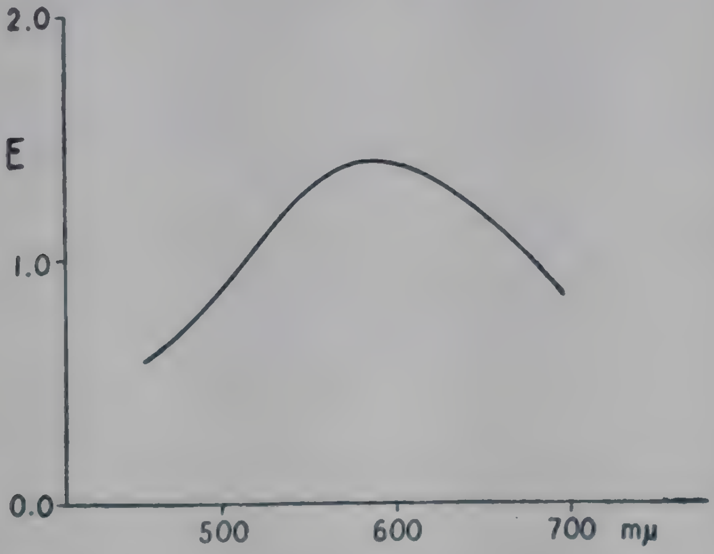


Fig. 9.6. Iodine color with starch.

26. "Gmelins Handbuch der anorganischer Chemie," 8th edition (1925–1941) (*B24*). A very complete listing of inorganic compounds and their properties including references to their absorption spectra.

General reference should also be made to the indexes of the abstract journals, especially *Chemical Abstracts* (*D6*), *Science Abstracts*, and *Biochemical Abstracts*.

For a discussion of the application of spectrophotometric data, good general review articles are to be found in the section by Ley (*B47*) in Vol. XXI of the "Handbuch der Physik," the sections by Ramart-Lucas (*B67*) and Lecomte (*B42*) in Vol. II, Part I, of Grignard's "Traité de chimie organique; the section by Martinet (*B54*) in Vol. II, Part II, p. 653, of Grignard's "Traite de chimie organique"; the section by Scheibe (*B70*) in Vol. IX of the "Hand- und Jahrbuch der chemischen Physik"; and Twyman and Allsopp (*B76*) "Practice of Spectrophotometry"; as well as the general references indicated in the bibliography.

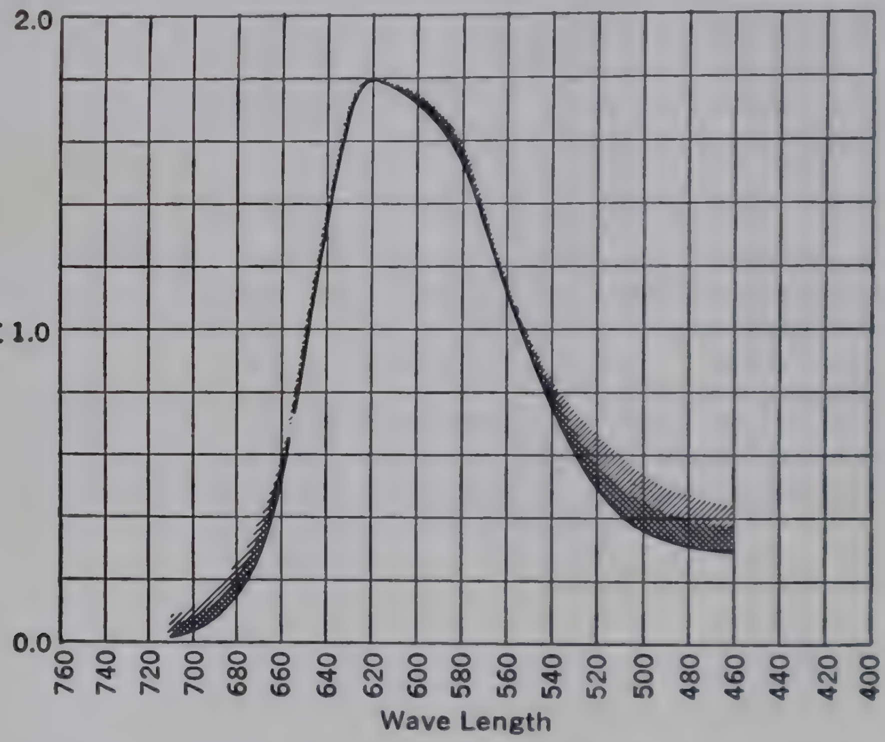


FIG. 9.7. Spectrophotometric curves for Agalma Black 10B (Brode [*C16*]). The inside line is the curve for the pure dye (10 mg per liter, thickness of solution 2 cm, temperature 25°C, in acetate buffer solution, *p*H 5.0). The curves of the 23 commercial samples lie within the shaded area, the majority of them within the heavily shaded area.

In connection with compounds of a biological nature there have been a number of compilations of absorption spectra data and methods such as those found in Miller's "Quantitative Biological Spectroscopy" (*B57*), Löwe's "Optische Messungen des Chemikers und des Mediziners" (*B52*), Loofbourow's "Borderland Problems in Biology and Physics" (*C127*), Heilmeyer's "Medizinische Spektrophotometrie" (*B27*), Schumm's "Spektrochemische Analyse natürlicher organischer Farbstoffe" (*B71*), or the compilation by Ellinger on the absorption spectra of natural products (proteins, sugars, etc.) in the "Tabulae Biologicae," Vol. XII (*B15*).

Transmission curves of colored glass and light filters have been listed in the publications of the Colorimetry Section of the Bureau of Standards (*D7*) and in manufacturers' publications, especially those of the Eastman Kodak Company, Corning Glass Company, and Jena Glass Works.

QUANTITATIVE ANALYSIS

In the application of absorption spectra methods to quantitative analysis one may measure the extinction coefficient directly if the compound to be examined contains a resonating group and is free from other resonating substances which produce absorption at the wavelength for the absorption band of this compound. In some cases where impurities prevent the direct determination one can take advantage of reactions of the resonating compound for which analysis is to be made, i.e., some other compound or reagent may be added which will produce a colored reaction whose intensity will give a direct measure of the quantity of the resonating compound that is present (Fig. 9.6).

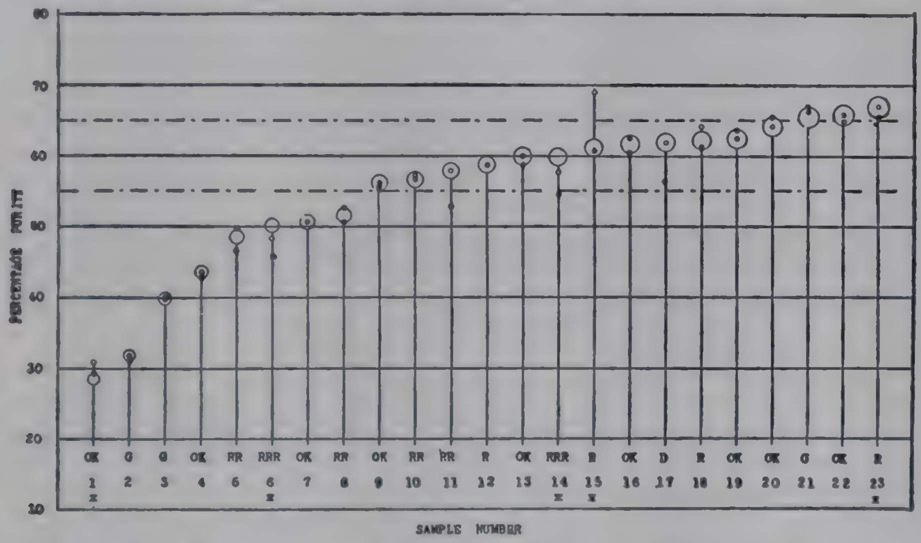


FIG. 9.8. Strength of commercial samples of Agalma Black 10B.

○ strength by dyeing test.
o titanous chloride titration.
• spectrophotometric method.

Above the sample number is given the "shade" of dyeing as compared with Sample 13.

OK = same as 13.
G = greener.
R = redder.
D = duller.
X = foreign sample.

Note that wherever the spectrophotometric value is decidedly at variance with the other methods there is also a decided red or dark shade in the sample indicating inpurities. (Brode [*C16*].)

In many dye laboratories the quantitative determinations of the amount of dye in a sample are made by the spectrophotometer, which gives an indication of the quality as well as the quantity of dye present. In this method the presence of salts or other nonabsorbing compounds will not interfere with the determination (Figs. 9.7 and 9.8). Slight amounts of colored impurities in a dyestuff can be detected and often identified both qualitatively and quantitatively by a study of the subsidiary dyes present. In a study of the commercial dyestuff Agalma Black 10B, it was found that the impurities were concentrated in the mother liquor so that the identification could be made from the residual solution after a 16 per cent dyeing (Fig. 9.9).

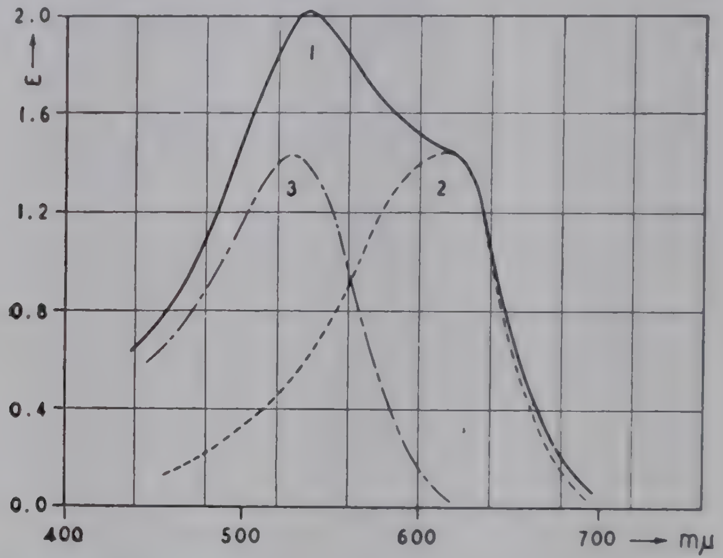


FIG. 9.9. Absorption spectra of:
(1) Mother liquor from a 16 per cent dyeing of a commercial sample of Agalma Black 10B whose shade was rated as RRR by dyeing tests.
(2) Agalma Black 10B spectrum.
(3) Impurity spectrum (Brode [*C16*]).

The amount of dye or other substance, in accordance with Lambert's and Beer's laws, can easily be determined from the known thickness and extinction values by means of the following formula:

$$c = \frac{\log I_0/I}{kd} = \frac{E}{kd}$$

From the known extinction coefficient (k) of the pure compound and the observed extinction (E), it is possible to calculate quite accurately the concentration (c) of the absorbing substance. This method is extensively used in the analysis and standardization of commercial dyestuffs and colorimetric reactions, without the necessity of purification or separation from other nonabsorbing materials, such as mineral salts, which are usually present.

In the quantitative estimation of vitamin A it has been shown that fish oils do not contain absorbing substances, other than vitamin A, which show an absorption band at 328 mμ. It is therefore possible to estimate accurately the amount of vitamin A in a sample by a determination of the extinction coefficient of a known concentration and thickness of the oil sample. Since the compound, vitamin A, is known from the standpoint of molecular size and composition, it may be assigned a specific extinction value for quantitative comparison. It has been agreed to use the factor

$$E_{1\text{ cm}}^{1\%} \times 2200 = \text{IU}$$

which indicates that a 1 per cent solution of the oil in a 1-cm cell will contain per gram, in its original oil sample, the number of international units equivalent to its extinction multiplied by 2200 (see experimental section page 340).

The methods of quantitative spectrophotometric analysis have been in practice for some time, as indicated in the "Manual on Quantitative Spectroscopic Analysis," published by Kruss (*B39*) in 1890 and revised in 1909. It is obvious that the use of spectrophotometric methods should be of considerably advantage in the examination of colored liquids and especially in the quantitative estimation of a colored impurity in a solution which is originally colored. Two examples of this type might be mentioned: (*a*) the determination of the *p*H concentration of a colored solution, and (*b*) the determination of the blood volume of a patient. In the second determination, a dye such as T-1824 (*o*-tolidine diazotized and coupled to 1-amino-8-naphthol-2,4-disulfonic acid), which has an absorption band at 505 mμ and a point of maximum transmission of the blood solution (Fig. 9.10), and which is not rapidly absorbed in the system, is injected in a known quantity into the blood stream. After a

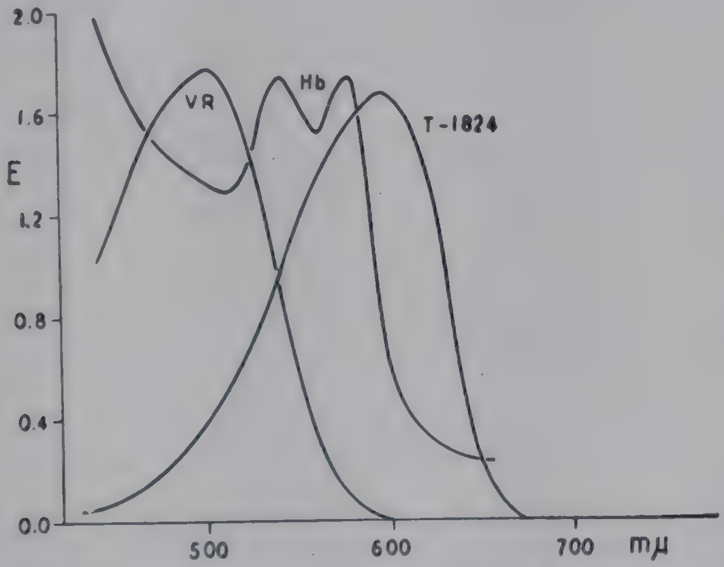


FIG. 9.10. Absorption spectra of hemoglobin (Hb) and dyes used for blood-volume determinations (T 1824 and Vital Red).

fixed time a blood sample is withdrawn and the amount of dye determined spectrophotometrically by setting the wavelength drum of the spectrophotometer at the absorption band position for the dye and measuring the extinction. From this value one subtracts the known hemoglobin absorption at this wavelength, and from a previously prepared standard the amount of dilution can be estimated, and hence the blood volume determined.

The spectrophotometer has been extensively used in inorganic as well as organic analysis, and one finds it almost indispensable in the purification of the rare earths, where the total color of the salt, as indicated by the area included in the absorption band, is low, but where the very intense nature of the absorption bands permits an accurate estimation of the amount of element present in a very dilute solution (Fig. 9.4). Another great advantage of the spectrophotometric method of analysis is the small amount of material required for analysis. By the use of micro absorption cells (Fig. 7.44) it is possible to make accurate observations on less than a cubic centimeter of solution, and to estimate the amount of dye in this solution when it may contain less than 0.01 gram per liter of original solution. The spectrophotometric method can be used not only to determine the presence of a small amount of a compound but also to measure the purity of a compound when the possible impurities may be colored substances

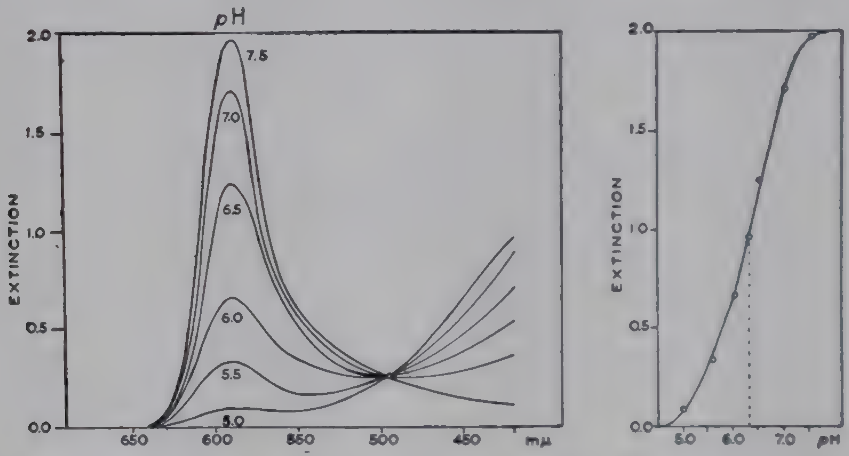


FIG. 9.11. Spectrophotometric determination of hydrogen ion concentration.

a. Absorption spectra of bromocresol purple at the indicated *p*H values. (Note isosbestic point at 498mμ.)

b. The dissociation curve calculated from the extinction and *p*H values. (Dotted line indicates dissociation constant for the indicator.) (Brode [*C15*].)

GENERAL APPLICATIONS

An important field of application of spectrophotometric methods is in the determination of conditions of state such as hydrogen-ion concentration, oxidation and reduction potential, the equilibrium between tautomeric forms, and the measurement of reaction rates. The following examples should illustrate the method of application and may suggest similar uses. In a study of indicators (*C15*) it has been shown that the change of *p*H value of the solution results in a change in intensity rather than wavelength shift of the absorption band, thus indicating the elimination of one resonating system and the formation of another. This change from one system to another is inversely proportional to the relative extinction coefficients, and hence there will be a point (Fig. 9.11)

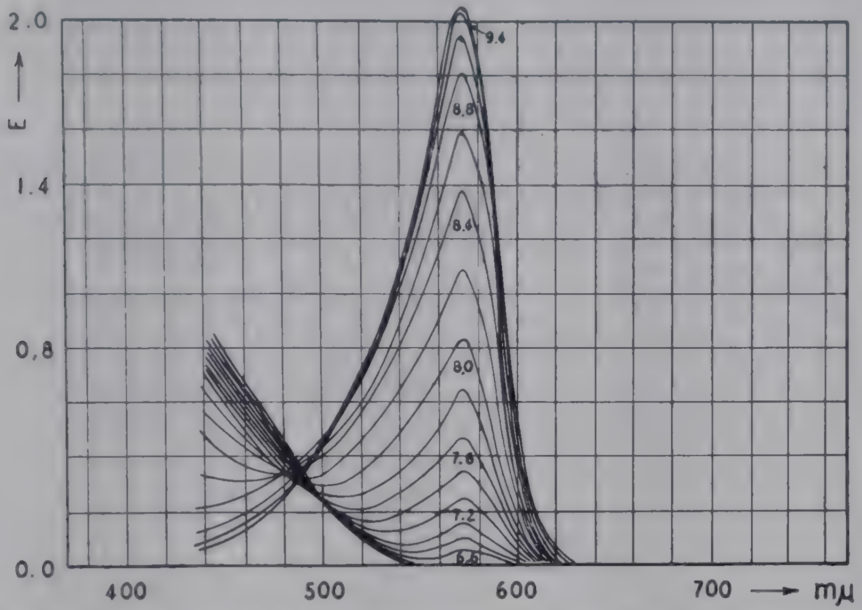


FIG. 9.12. Spectrophotometric determination of hydrogen-ion concentration; simple indicator (cresol red), (*C15*).

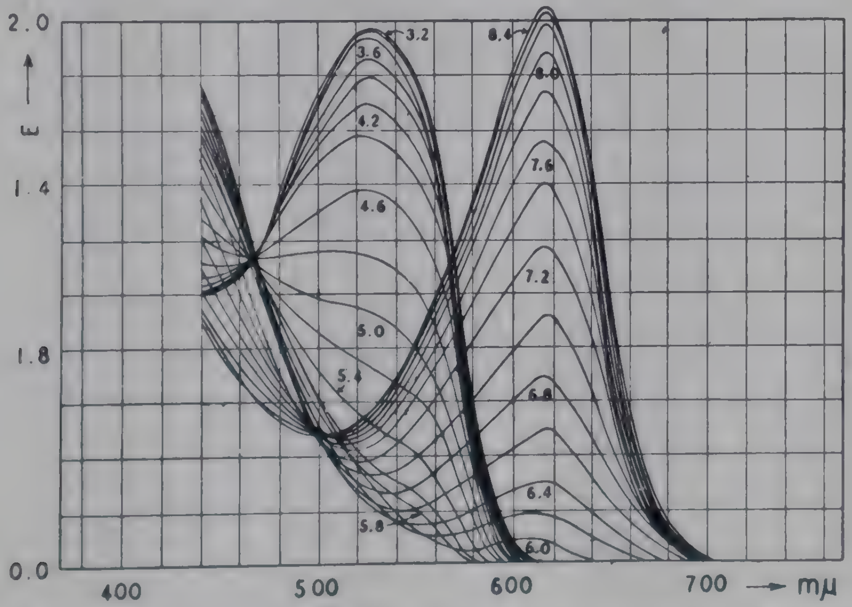


FIG. 9.13. Spectrophotometric determination of hydrogen-ion concentration; mixed indicator (methyl red + bromothymol blue). (Note isosbestic points at 467 and 500 mμ.) (*C15*.)

where the extinction curves should have a common value at any *p*H concentration. Such a point is known as an isosbestic point (point of equal extinction [*C192*]), and the ratio between the extinction at this point and the extinction at the absorption band maximum will provide a means of indicating the *p*H concentration of the solution which will be independent of the concentration of the indicator used.

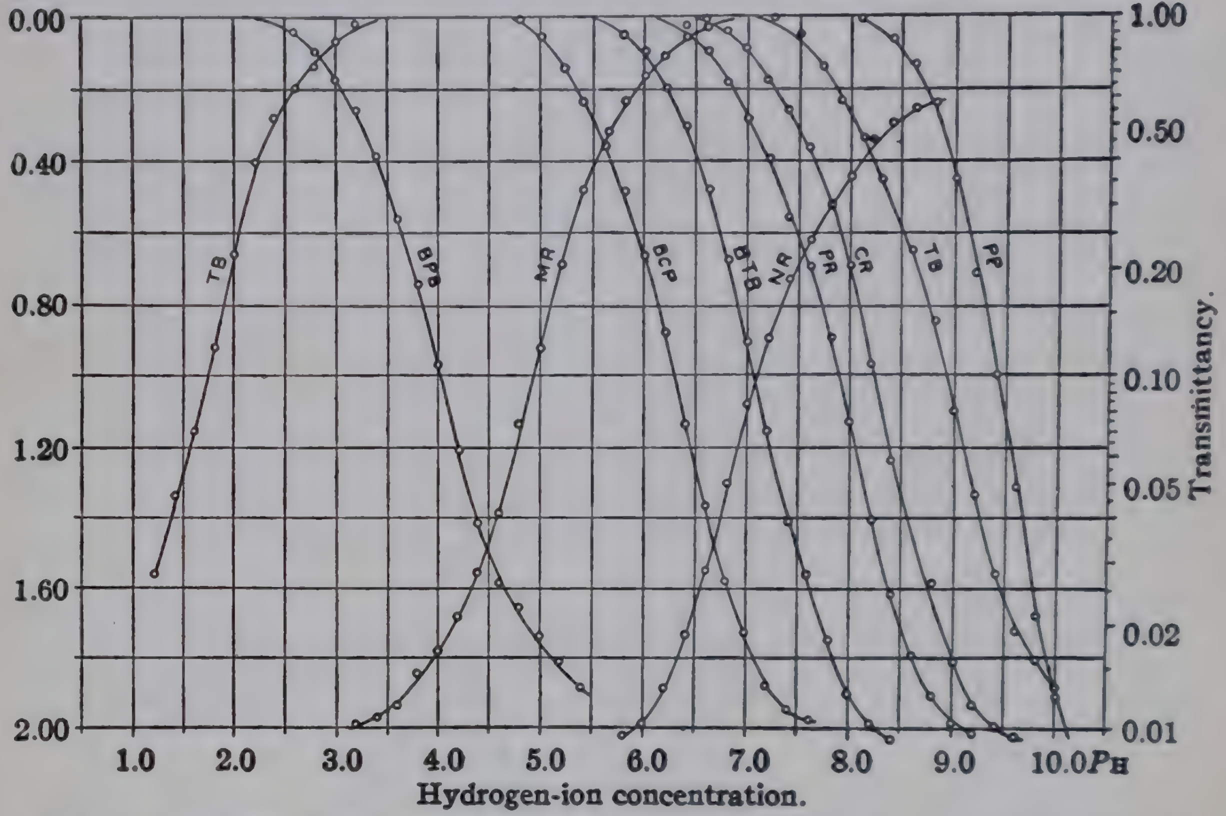
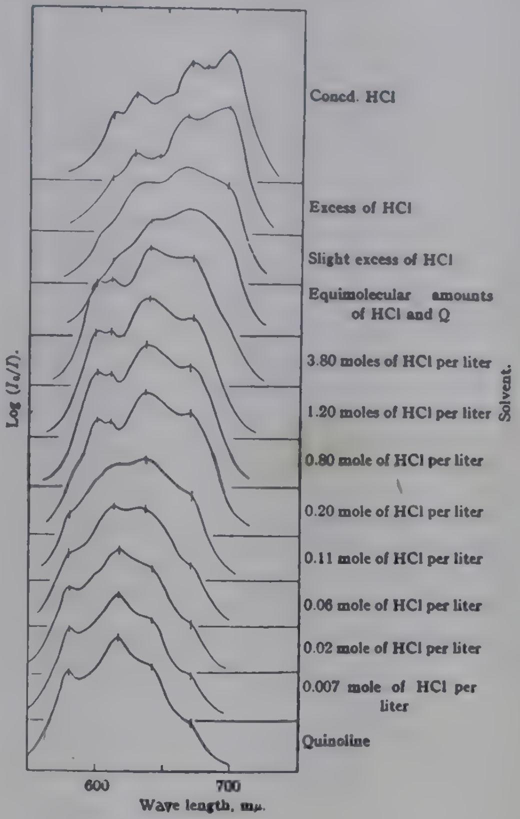


FIG. 9.14. Spectrophotometric determination of hydrogen-ion concentration; relation between the extinction coefficient of band maxima and *p*H of solution for the following indicators: thymol blue (TB), bromophenol blue (BPB), methyl red (MR), bronocresol purple (BCP), bromothymol blue (BTB), neutral red (NR), phenol red (PR), cresol red (CR), and phenolphthalein (PP). (Brode [*C15*].)

In the determination of reaction rates and tautomeric equilibria, one may ascertain the degree of hydrolysis, association, dissociation, enolization, etc., by the measurement of the absorption spectra of compounds that produce different spectra before and after the reaction occurs. As an example of such determinations the study of the absorption spectra of cobalt chloride in a quinoline-hydrochloric acid system may be considered. It will be noted in Fig. 9.15 that, at an acid concentration of approximately one mole per liter, the formation of a complex is definitely indicated by the well-defined absorption pattern. The existence of free *keto* and aldehyde groups in sugars, the conditions in tautomeric equilibria between the *enol* and *keto* forms, the formation of coordination complexes and chelated rings (Fig. 9.16), and the existence of intermediate compounds in a series of reactions can be indicated by spectrophotometric methods. Dimroth has shown the application of time or reaction rates to the irradiation change in certain sterols (*C73*) (Fig. 9.17). Brode and Magill have made a similar time extinction study of the antimony trichloride color reaction with oils containing vitamin A (*C45*)

FIG. 9.15. The change from the "Py-Q" (pyridine-quinoline) system, through the "intermediate" system to the "HX (halogen acid) system, caused by the addition of hydrochloric acid to a solution of cobalt chloride in quinoline. (The curves in this figure are only a few of the some 50 curves, observed at various quinoline-hydrochloric acid concentrations. They have been chosen to show characteristic stages or transition points in the change of the absorption systems. The concentrations of cobalt chloride in all solutions were approximately 0.0043 mole per liter.) (Brode [*C25*].)



and have demonstrated the feasibility of rapid observations on a fading solution to determine the reaction rate and, by extrapolation, the theoretical initial extinction value.

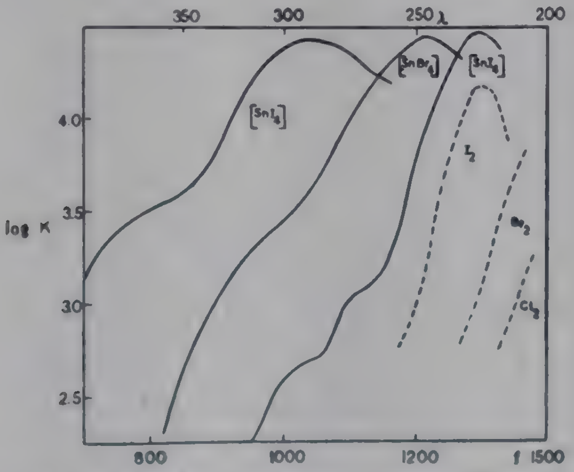


FIG. 9.16. Coordinated tin-halogen complexes. (Fromherz and Walls.)

The analysis of chlorophyll extracts for the proportion of chlorophyll A and chlorophyll B in the mixture has been expedited by means of absorption spectra methods. In Fig. 9.18 it will be noted that chlorophyll

B has a maximum at 457 mμ (dotted line) which is nearly a minimum point in the chlorophyll A curve (solid line). Using control values for the "A" concentration at 410 mμ or 666 mμ and comparing with values at 457 mμ it is possible to estimate the amount of chlorophylls A and B in a mixture of the two pigments (*C211*).

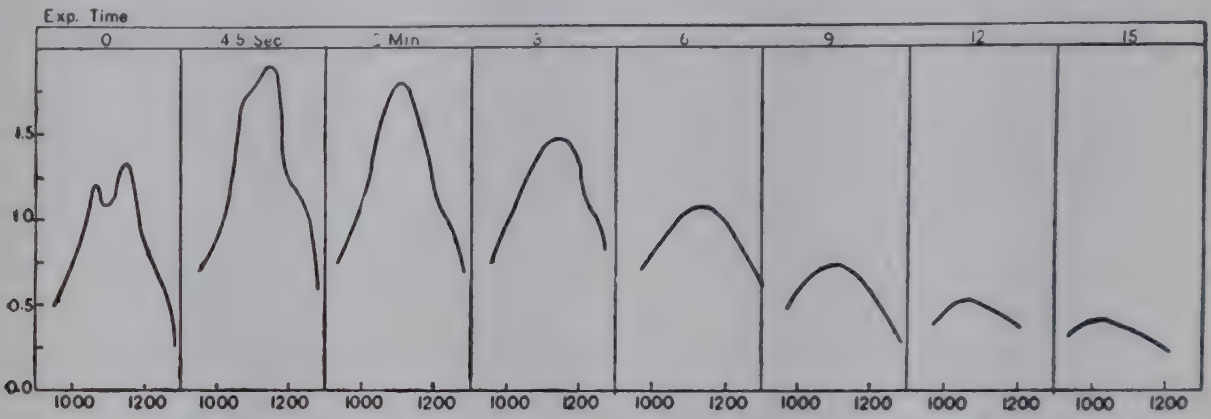


FIG. 9.17. Effect of irradiation on sterols (Dimroth [*C73*]).

Miller (*B57, C144a*) has described methods for the estimation of absorbing constituents in binary systems (Fig. 9.19) and more complicated ternary and quaternary systems such as mixtures of lycopene, beta carotene, and alpha carotene, and combinations of these constituents with mixtures of chlorophylls A and B. The sharp and characteristic absorption of natural pigments and compounds provides a convenient method of estimation of concentration and detection of alteration in the pigment structure (Fig. 9.20).

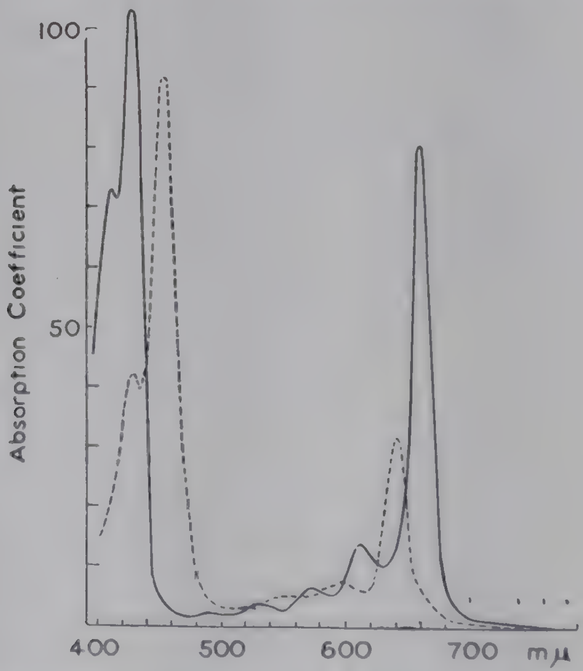


FIG. 9.18. Absorption spectra of chlorophyll A (solid line) and chlorophyll B (dotted line.) (Miller [*C211*]).

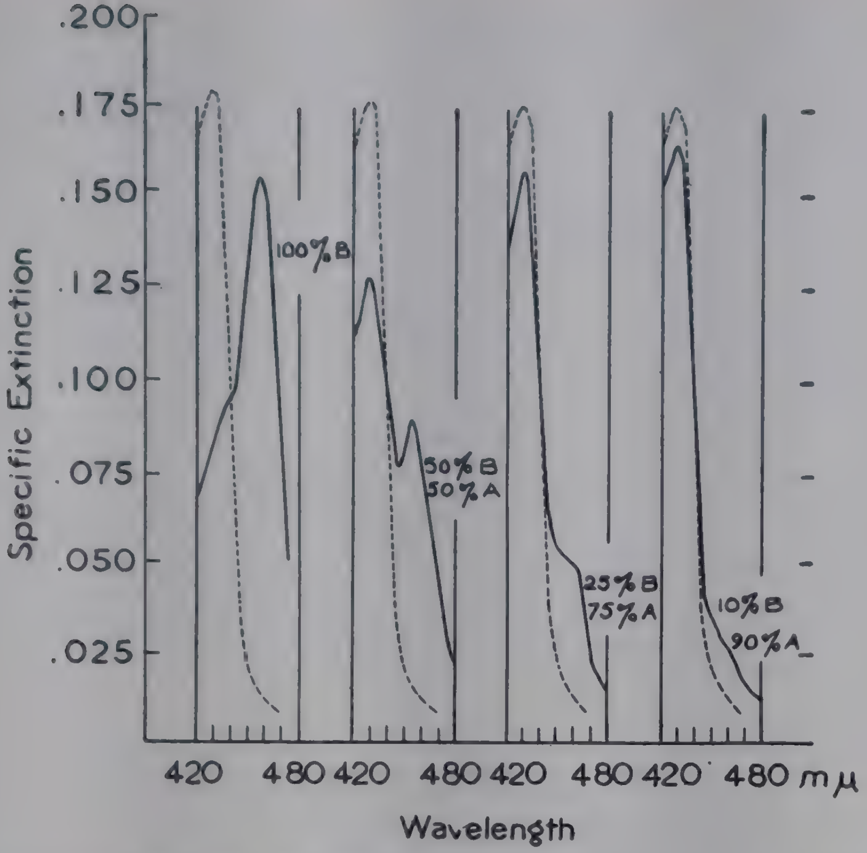


FIG. 9.19. Absorption spectra of mixtures of chlorophylls A and B (solid line) and chlorophyll A (dotted line) (Miller [*C211*]).

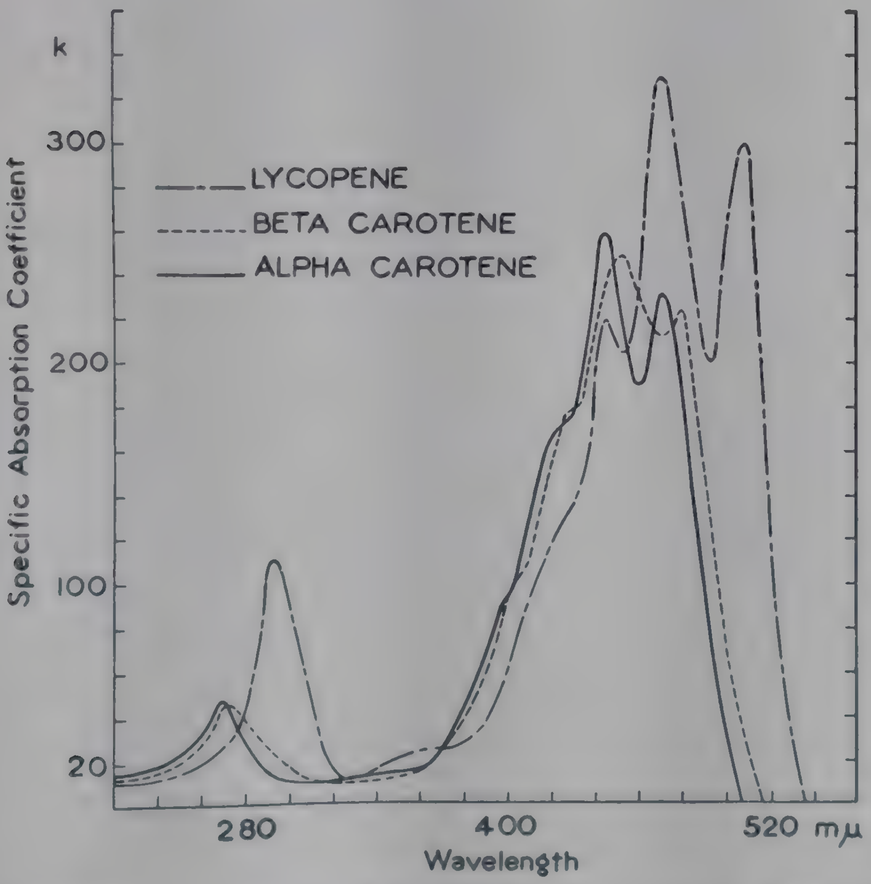


FIG. 9.20. The absorption spectra of lycopene, beta carotene, and alpha carotene (Miller [*C211*]).

The interrelation between absorption spectra and refractive index or optical rotation is indicated by the formulas for the calculation of these effects, in which the wavelength or frequency of the absorption band is an important factor. In the study of rotatory dispersion of asymmetric organic and inorganic compounds, it has been possible to analyze the absorption spectrum and the rotatory dispersion curve obtained, so as to indicate the portions of the molecule that are responsible for the various effects which add together to produce the observed effect (Figs. 9.21, 9.22, and 7.30).

PREDICTION OF STRUCTURE

One of the most important uses of absorption spectra data has been in the prediction of structure and proof of synthesis. Many of the complex naturally occurring compounds are available in such small amounts, or are so unstable, that they cannot readily be isolated from their surrounding media. It is fortunate in many of these cases that the surrounding medium does not absorb light or does so only in a limited spectral region, so that the substance often may be characterized by its absorption, and the concentration of active constituent accurately estimated (e.g., vitamin A). One often may predict certain structural features from the absorption spectra alone by comparison with similar compounds of known structure. Chemical tests may show the presence of certain groups, but not necessarily the position of such groups in the complex molecule. By comparing the absorption spectra of existing or synthesized compounds of known similar structure with the absorption spectrum of the unknown compound, one can eliminate certain structural possibilities

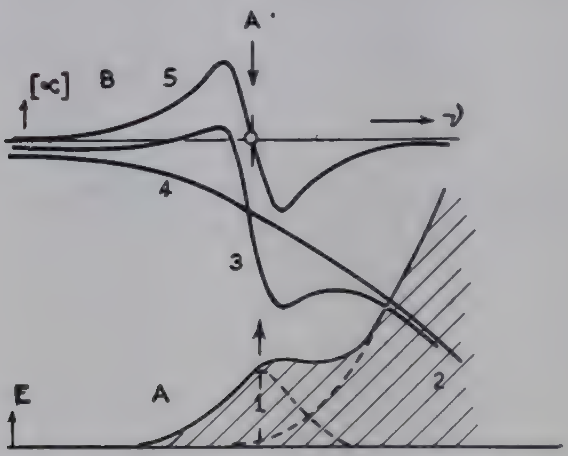


FIG. 9.21. Relation between optical rotation (*B*) and absorption (*A*). Observed rotation (3) is resolvable into curves (5) and (4). Curve 5 is associated with the absorption center of absorption band (1) and is based on the Natanson-Drude equation with an inflection at 0 rotation at the frequency of the absorption band.

(Figs. 9.23 and 9.24). Such a procedure is illustrated in the determination of the structure and in the synthesis of vitamin B$_1$ (*C205*). The final proof of structure is the synthesis of the predicted structure and its test, spectrophotometrically and otherwise, to show identity of the two compounds.

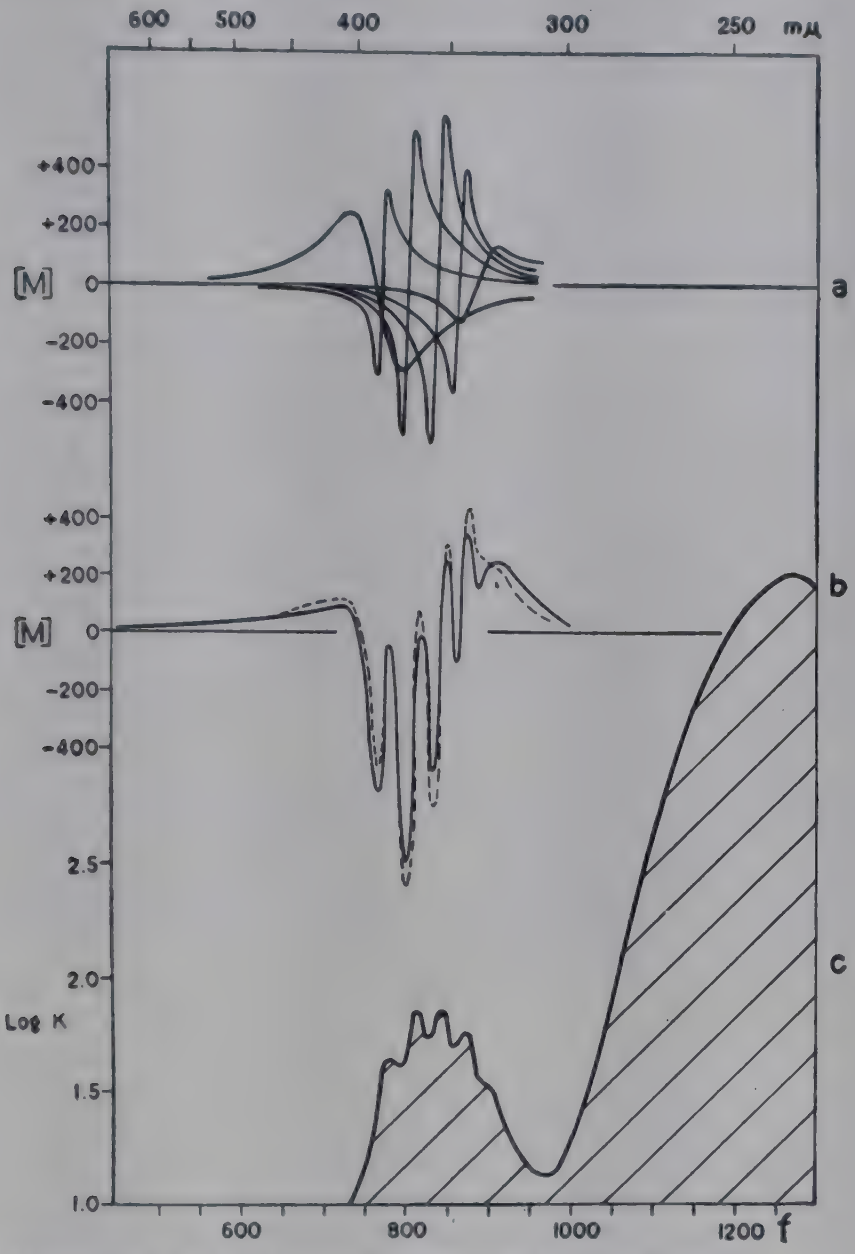


FIG. 9.22. Absorption and rotatory dispersion of octyl nitrite.
a. Rotatory dispersion analysis based on absorption band centers.
b. Summation of rotatory dispersion analysis (dotted).
Observed rotatory dispersion (solid).
c. Observed absorption spectrum (Kuhn and Deutsch [*C120*]).

As one of the first steps in the determination of the structure of vitamin B$_6$ (*C82*) it was demonstrated that the vitamin gave an absorption spectrum which was similar to that of β-hydroxy pyridine. A further study of the absorption spectra of vitamin B$_6$ at various *p*H values

(Fig. 9.25) showed a characteristic series of band equilibria with definite isosbestic points. Comparison of these data with the absorption spectra of β-hydroxy pyridine derivatives of known structure pointed to 2-methyl-3-hydroxy-4,5-di(hydroxymethyl)-pyridine as the structure of vitamin B_6.

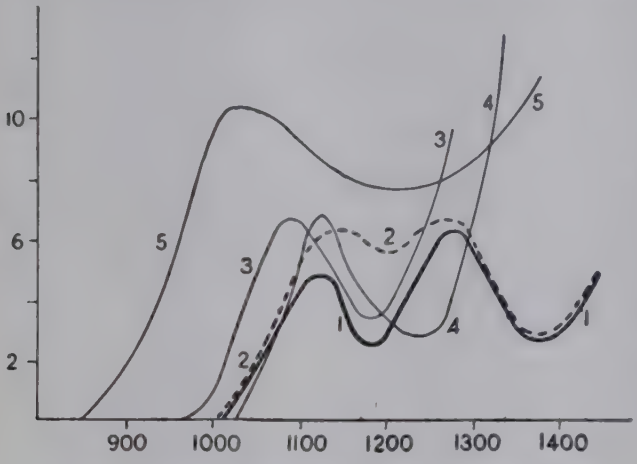


Fig. 9.23. Absorption spectra of the ammonia cleavage product of vitamin B_1 and related pyrimidines. (1) Cleavage product. (2) 2,5-Dimethyl-6-aminopyrimidine. (3) 4,5-Dimethyl-2,6-diaminopyrimidine. (4) 5-Ethyl-4,6-diaminopyrimidine. (5) 4-Methyl-5,6-diaminopyrimidine. (Williams and Ruehle [*C205*].)

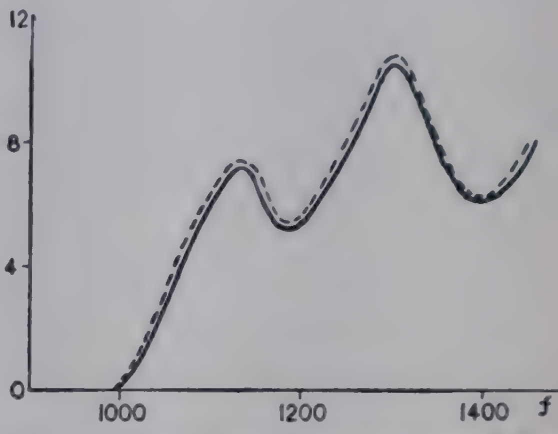


Fig. 9.24. Absorption spectra of the natural (-----) and synthetic (———) vitamin B_1 hydrochlorides [3-(4-amino-2-methyl-5-pyrimidylmethyl)-5-(2-hydroxyethyl)-4-methylthiazolium chloride hydrochloride] (Williams, Ruehle, et al. [*C205*]).

The prediction of structure from the absorption spectrum requires a large amount of well-worked-out data, and, even with these data available, the prediction often will be uncertain. The data might be divided into two types: (*a*) the influence of nonchromophoric or weighting groups

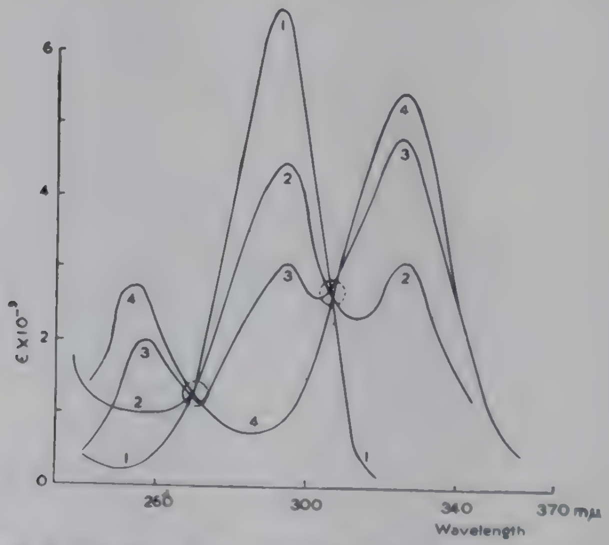


Fig. 9.25. Influence of hydrogen-ion concentration on the absorption spectrum of vitamin B_6 (Folkers [*C82*]). (Note isosbestic points at 270 and 310 mμ.)

on chromophores, and (*b*) the influence of one chromophore on another. The studies by Wulf (*C209*), Pestemer (*C159*) (Fig. 9.26), and Brode (*C49, C50*) provide examples of this type of work, i.e., the influence of nonchromophoric groups attached to chromophoric groups, as shown in the change of the extinction and frequency of absorption bands. In the second class of compounds involving two chromophores in the same molecule, it has been demonstrated that certain linkages, such the as —CH_2— and more especially the —CH_2—CH_2— and longer chain —$(CH_2)_n$—, act as insulating pads between the two resonating groups and fail to transmit vibration from one chromophore to another (Figs. 8.42 and 9.27). It might also be pointed out that the placing of chromophores adjacent to one another may result in an interference action and a reduction of the expected intensity (Fig. 8.44), whereas in a conjugated coupling there appears to be a multiplication effect resulting in a bathochromic and hyperchromic effect (Fig. 9.28).

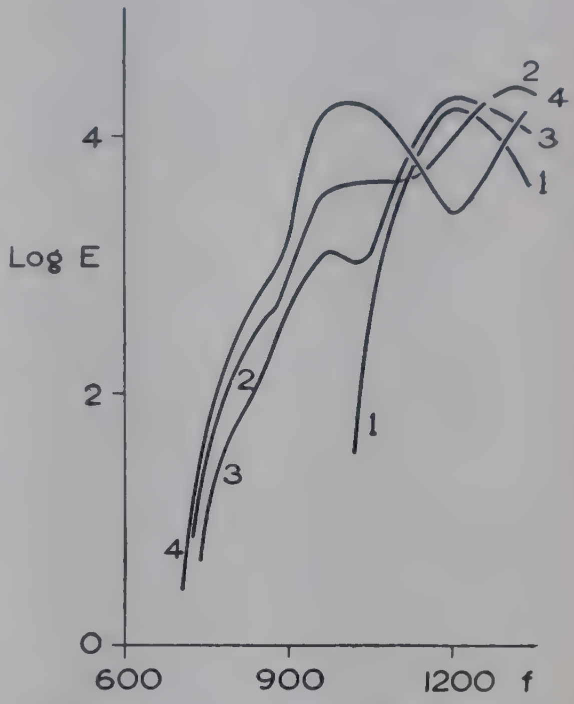


Fig. 9.26. Variation of extinction with a change in the position of substitution. The absorption spectra of diphenyl (1), *o*-nitrodiphenyl (2), *m*-nitrodiphenyl (3), and *p*-nitrodiphenyl (4), in hexane. (Pestemer [*C159*].)

In a study of molecules containing two chromophores, Brode and Piper (*C50*) have shown that the connecting of the two chromogens by a methylene (—CH_2—) or ethylene (—CH_2—CH_2—) linkage gives almost complete insulation of the separate chromophores since the absorption spectra of the molecule with two chromophores is nearly identical with the summation of the absorption spectra of two separate molecules, each containing one of the chromophores. The coupling of two chromophore groups through a common aromatic ring (type 7, Fig. 9.27) may alternately involve the center or connecting ring as the resonating end for each azo chromophore or the center ring may be part of a resonator involving both chromophores in combination to form a larger chromophore. The first effect will operate to some extent to reduce absorption intensity (i.e., two chromophores sharing a single resonator). The last effect (larger resonator) will result in the formation of a new band at a lower frequency, characteristic of the longer resonating structure.

The separation of the chromogens by a covalent linkage (type 8 in

Fig. 9.27) yields a structure in which both separate dyes can resonate independently and at the same time, or the covalent linkage can act as a resonance transmitter to form a larger resonating structure and hence a lower frequency of absorption. In the last case indicated in the investigation (Dye 11 in Fig. 9.27) the two resonating structures are separated by an ethenylene linkage (—CH═CH—) which is known to be a resonance transmitter and promoter, hence it is to be expected that the (—CH═CH—) linkage will favor the resonance of the molecule as a whole in its longer resonating form to the exclusion of the resonance possible in the separate monoazo chromogens.

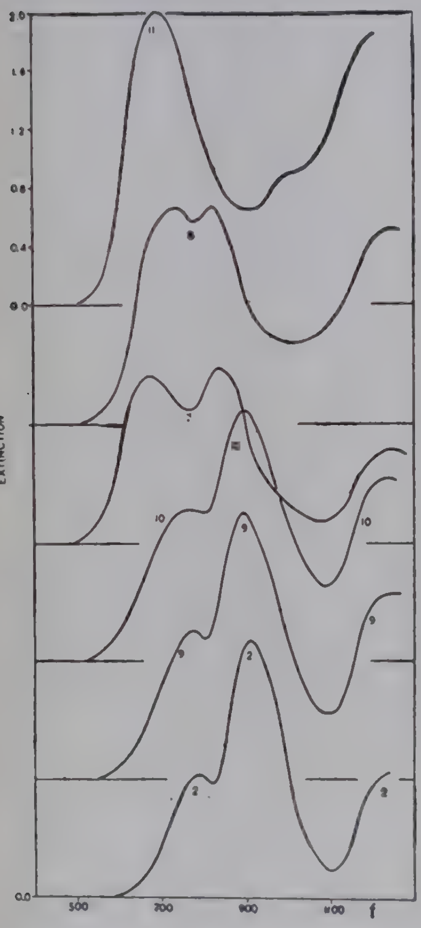
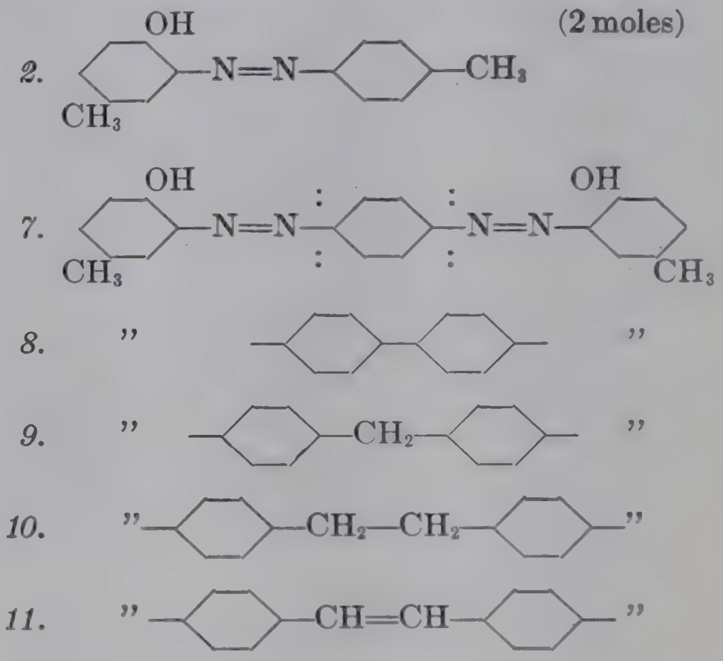


Fig. 9.27. Absorption spectra of chromophores linked by conjugated and non-conjugated groups (Brode and Piper [*C50*]).



Increasing the number of conjugated linkages between chromophoric resonators (Fig. 9.28) results in a continued bathochromic and hyperchromic effect, although the rate of increase becomes proportionally less (Fig. 8.15 and 8.31) so that there is a limit to the shift and intensity increase that can be produced by lengthening the conjugated chain. There also seems to be a limit from the standpoint of synthetic preparation difficulties and stability of the highly conjugated compounds. The attachment of substituent or weighting groups along the conjugated chain which connect the two resonating groups may result in a marked variation in the absorption spectrum, much as the weighting of a vibrating string at a definite point will set up an entirely different vibrational system.

Brooker (*C55*) has noted in a study of cyanine and thiazole dyes that, if two end resonators or vibrators (A and B) in a resonating chain are of a similar basicity (Fig. 9.29) but not identical in resonating characteristics, the unsymmetrical compounds produced (A—(CH═CH)$_n$—B) will have absorption maxima which are the mean value between the absorption maxima of the corresponding symmetrical compounds A—(CH═CH)$_n$—A and B—(CH═CH)$_n$—B (Fig. 9.30). If the end groups A and B differ in basicity, however, the mixed or unsymmetrical compound

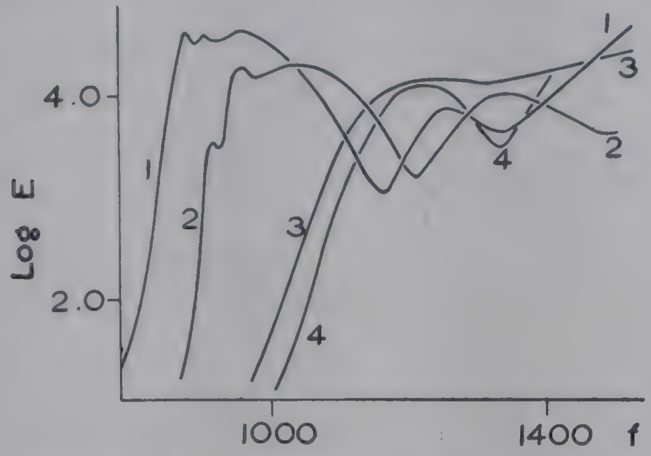


Fig. 9.28. The influence of the separation of chromophores on the absorption spectra of compounds containing more than one resonating group. Diphenyl (4), 1,1-diphenylethylene (3), 1,2-diphenylethylene (2), and 1,4-diphenyl-1,3-butadiene (1). (Castille [*C60*], Brode and Magill [*C45*].)

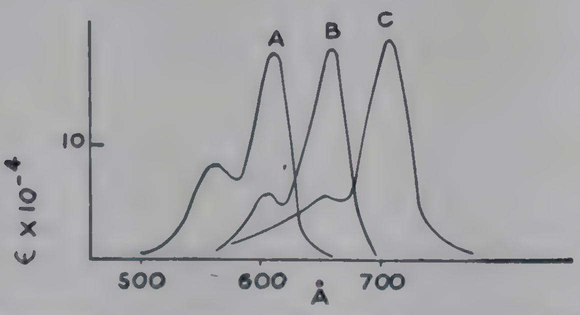


Fig. 9.29. Absorption spectra of cyanine dyes, 1,1′-diethyl-2,2′ (A), 2,4′- (B), and 4,4′-carbocyanine iodide (C) (Brooker [*C55*]).

A—(CH═CH)$_n$—B will have an absorption maxima at a lower wavelength than the arithmetic mean of the maxima of the two symmetrical compounds. Furthermore, as the number of the ethenylene linkages increases from 0, to 1, to 2, etc., the reduction from the mean or average of the unsymmetrical becomes greater. A lower basicity difference of A and B results in a smaller deviation.

The change from a linear increase of the wavelength of the absorption band (in a series of polyenic compounds) to a converging series (linear on a λ^2 scale) has been used by Brooker as a means of classifying the degeneracy of the chromophoric chain. In the degeneracy classification the two examples given, cyanine dyes (Fig. 9.30) and diphenyl polyenes (Fig. 8.15), rank as high and low values in the grouping of a number of polyenic series.

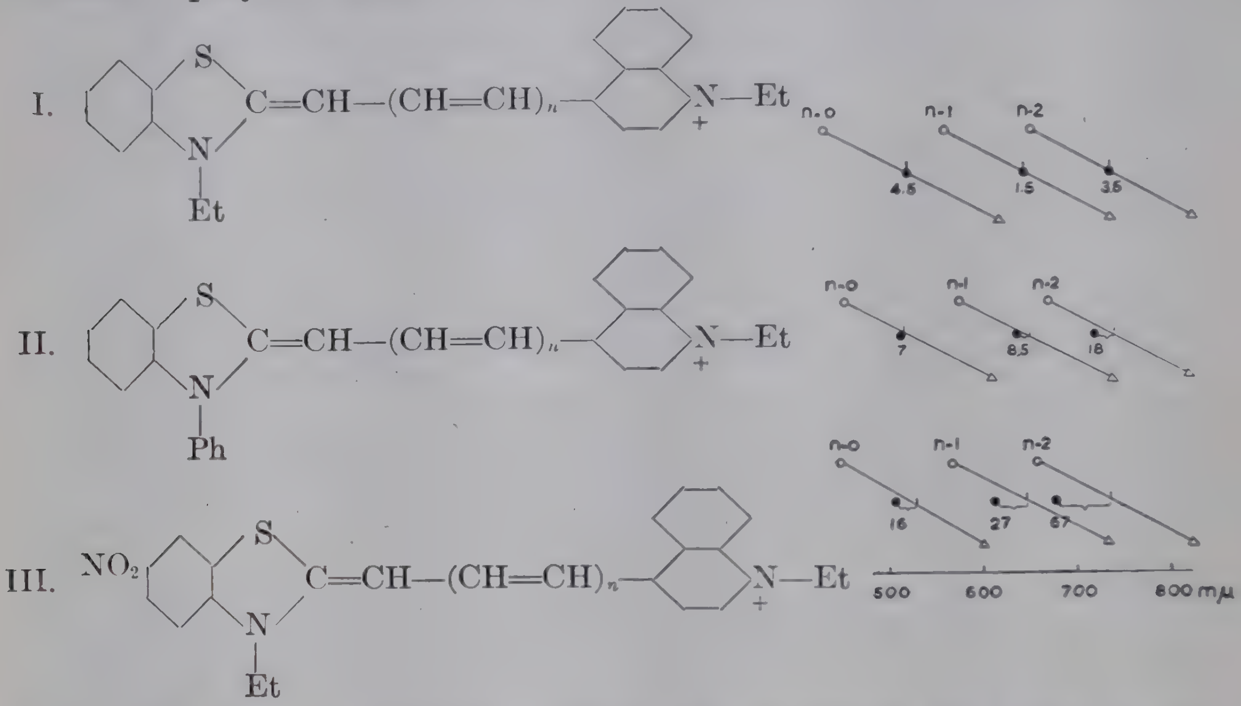


FIG. 9.30. Position of maximum of absorption of symmetrical and mixed polyenic dyes. (n indicates number of ethenylene linkages; o, the position of the absorption maxima of the symmetrical thiazole dye; Δ, the position of the absorption maxima of the symmetrical cyanine dye; and ● the position of the corresponding mixed dye ([formulas at left of cut]). Note that an increase in negativity of the thiazole ring results in a marked deviation of the mixed dye maxima position without changing the symmetrical dye maxima (Brooker [*C55*]).

A change in the character of the resonating group, such as the replacement of sulfur by selenium (*C9*, *C81*), in a molecule in which the replaced group is an active part of the resonator, will result in a marked bathochromic and hyperchromic effect, provided that the substituting group is a more powerful resonator. The effect produced in this case is greater than would be predicted by increased molecular weight alone. A decrease in the frequency of the absorption band (bathochromic effect) may be produced by changes within the molecule which may increase the conjugated path over which vibration may be transmitted, as is shown in the absorption spectra of the isomeric dibenzopyrenes (Fig. 9.32) (*C63*). A change in the position of substitution of a nonresonating substituent, in a similar type of compound, produces very little change in the absorption spectra (Fig. 9.33) (*C49*).

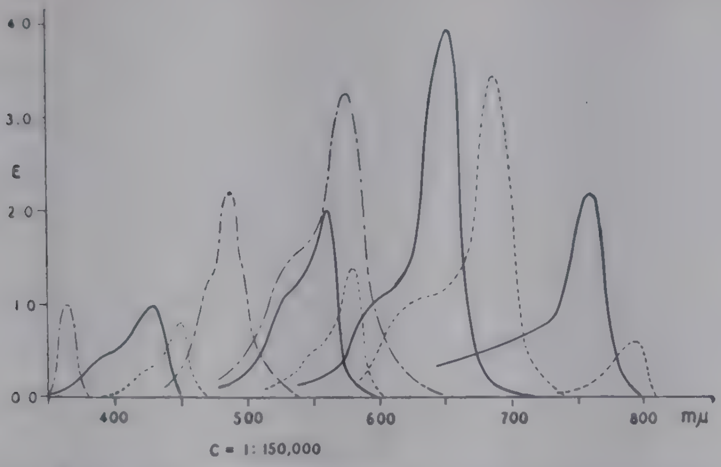
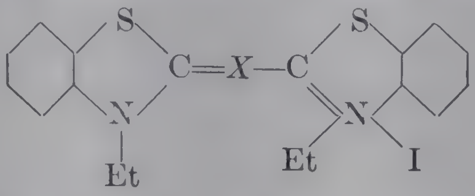
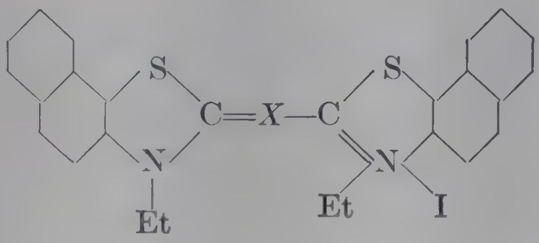


FIG. 9.31. Absorption spectra of some thiazole dyes.



Solid-line curves from left to right indicate above formula with *X* equal to (=CH—), (=CH—CH=CH—), (=CH—CH=CH—CH=CH—), and (=CH—CH=CH—CH=CH—CH=CH—). Dot-dash curves from left to right indicate compounds similar to the first three above but with two oxygen atoms replacing the sulfur in the molecule. Dot curves from left to right indicate the corresponding dyes with the type formula:



(All curves calculated to a solution concentration of 1 : 150,000 in methyl alcohol.) (Fisher and Hamer [*C81*].)

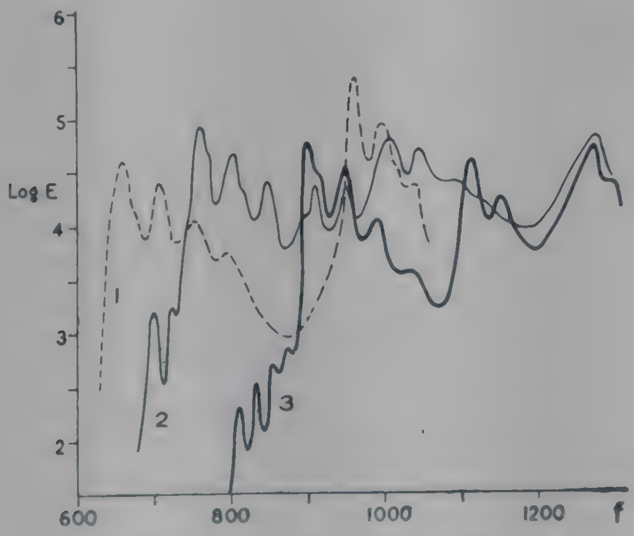


FIG. 9.32. Absorption spectra of 3,4-9,10-dibenzpyrene (*2*), 3,4-8,9-dibenzpyrene (*1*) and pyrene (*3*) (Clar [*C63*].)

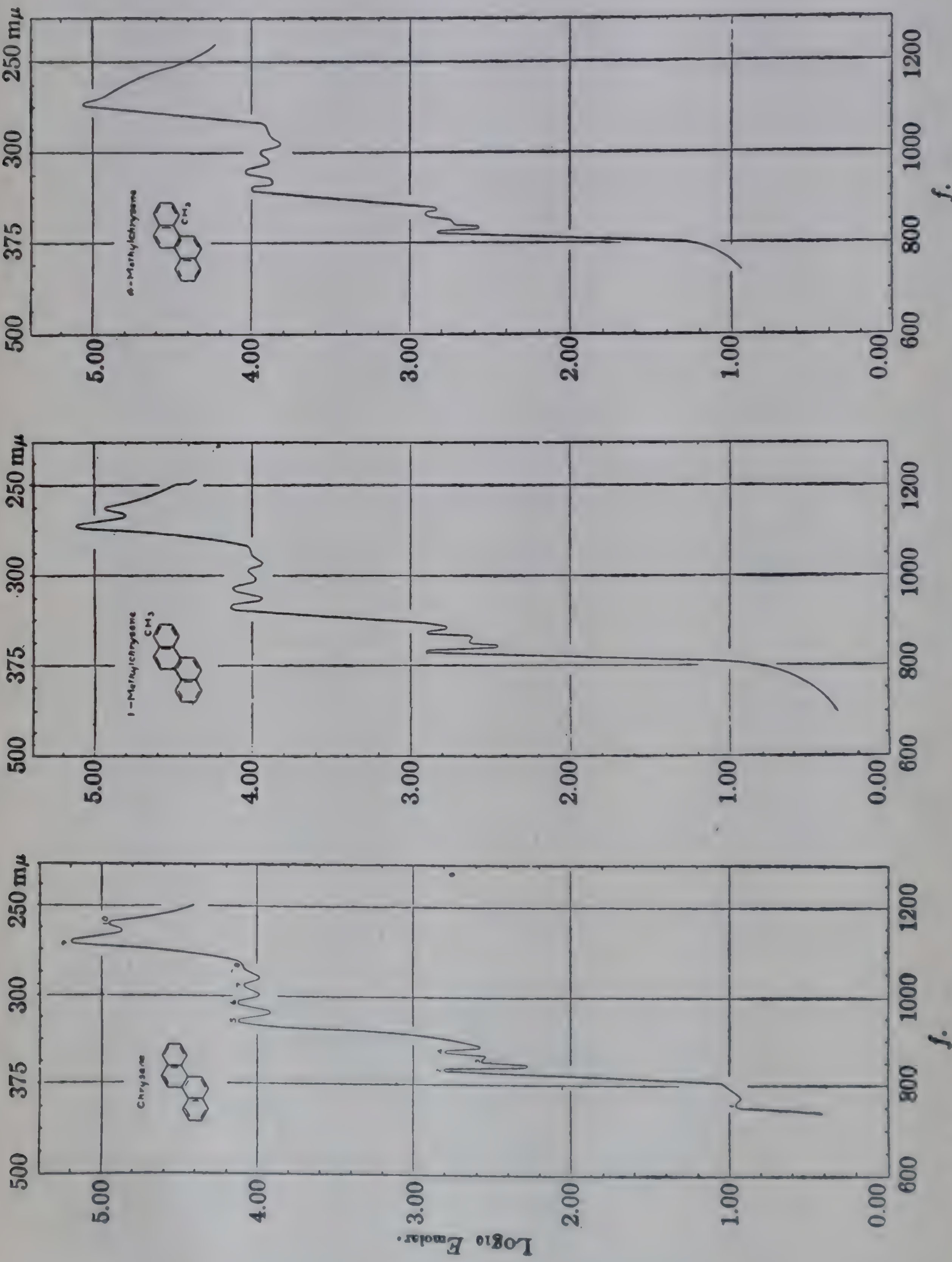


FIG. 9.33. Absorption spectra of chrysene and isomeric methyl chrysenes (Brode and Patterson [*C49*]).

The combination of metal ions with resonators in a covalent or coordinate linkage results in enhanced extinction values as well as shifts of the band frequencies (*C17, C47*) (Fig. 8.9). If the metal is itself of a resonating character, band combination effects may take place similar to those observed in the combination of two organic resonators (*C38*) (Fig. 9.34). The combination of nonresonating metal ions with organic resonators by covalent linkage results in an increased mass of the resonator as well as a change in the electron distribution. Two distinct effects are thus produced in the spectrum of the molecule, (*a*) a shift of the spectra to lower frequency (as could be predicted from increased mass of the resonator) and (*b*) a shift of band intensity to the first or low-frequency band (Fig. 9.35) (*C118*).

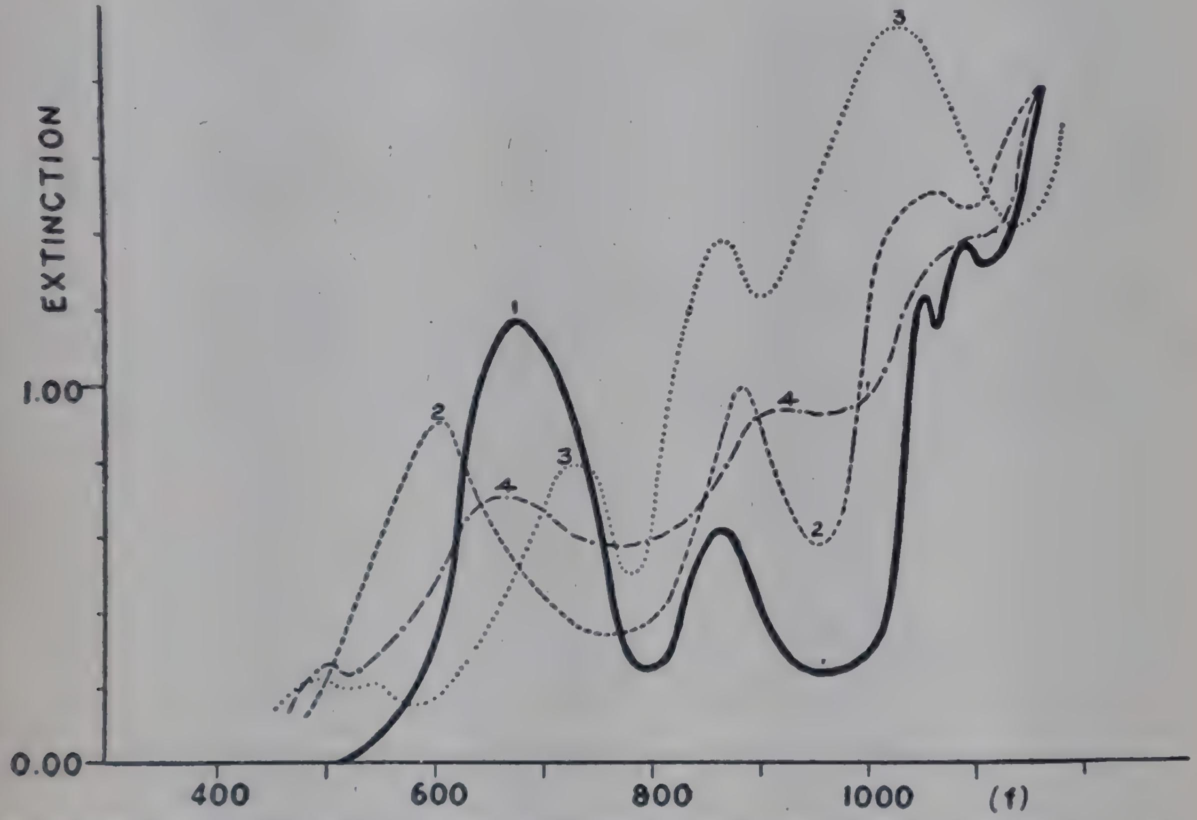


Fig. 9.34. Influence of copper (2), chromium (3), and iron (4) coordination on the absorption spectrum of a simple azo dye (1) (Brode and Ernsberger [*C38*]).

The shift of intensity to the low-frequency component of the absorption band and the frequency reduction due to increased mass is demonstrated also in the covalent linkage on anions as well as cations to a resonating structure as shown in the spectra of $CoCl_2$, $CoBr_2$, and CoI_2 (Fig. 8.9) (*C47, C25*).

General Summary of Color and Constitution

In conclusion it may be pointed out that electronically like substances, i.e., compounds that have a similar electronic structure but differ in weighting or chromophore size, may be assumed to give similar spectra.

From this statement it would seem that *p*-tolylazophenol and cobalt chloride in concentrated hydrochloric acid should have an electronic or resonating structure of much the same sort, since their absorption spectra are similar. The analogous shift of absorption bands of these compounds in neutral and basic solvents would provide additional support for this conclusion (Fig. 9.36). It may be further pointed out that nonconjugated chromophores in the same molecule produce essentially the added effects of the two separate groups, whereas conjugated chromophores produce a marked bathochromic and hyperchromic effect.

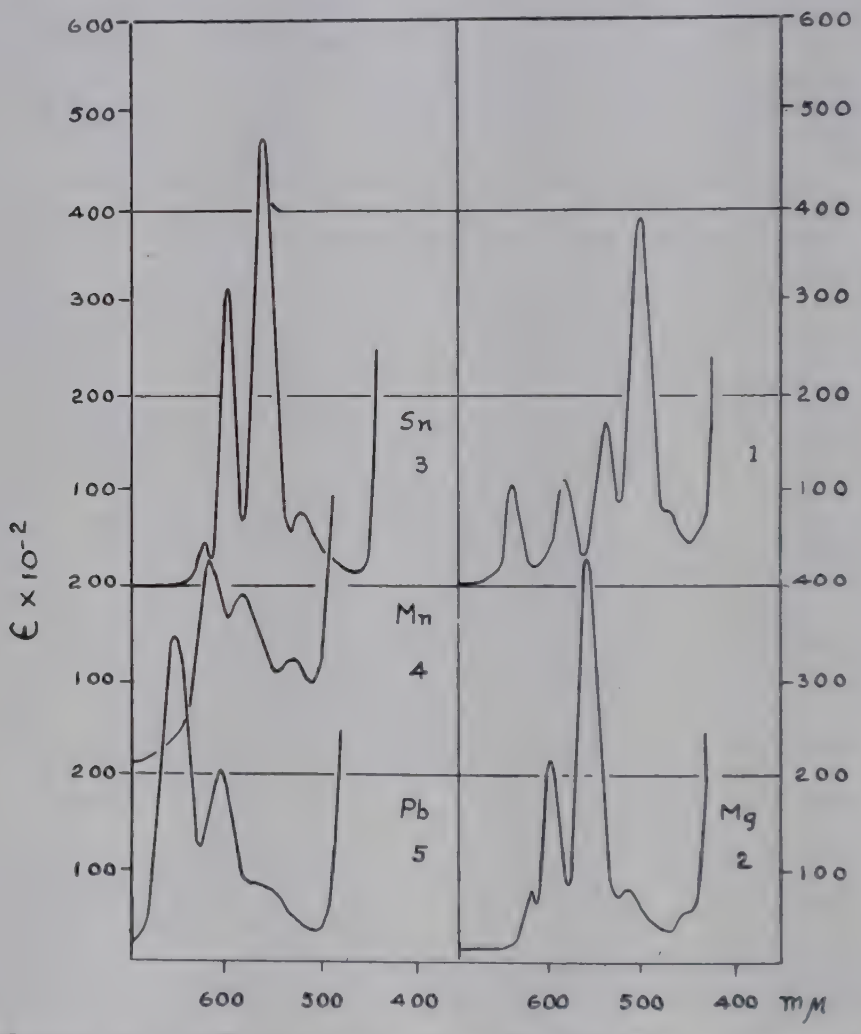


Fig. 9.35. Influence of coordinated magnesium (2), tin (3), manganese (4), and lead (5) on the absorption spectrum of a synthetic porphyrin (1) (Knorr and Albers [*C118*]).

A brief indication of the frequency values of various chromophores was given in Chapters VI and VIII (see also Tables 8.2 and 10.1). However, no satisfactory solution has been obtained for a mathematical expression for the vibration effects in a complex organic molecule. It would seem that, in view of the simple nature of the absorption spectrum of many of the more complex molecules, the ultimate explanation should involve a simple expression which would consider the chromophore as a whole rather than the inner and interatomic effects.

Brooker has shown that in normal cases the displacement of wavelength is directly proportional to the character of the resonator parts involved. Comparing the three molecules A-A, A-B, and B-B, the wavelength of the absorption band of A-B should be the mean of the corresponding values of the A-A and B-B bands, provided that A and B are of a similar basicity (*C55*). It has also been shown that the band displacement caused by an increase in the number of ethenylene linkages, (—CH═CH—), between A and B is approximately linear on a wavelength scale (Fig. 9.30).

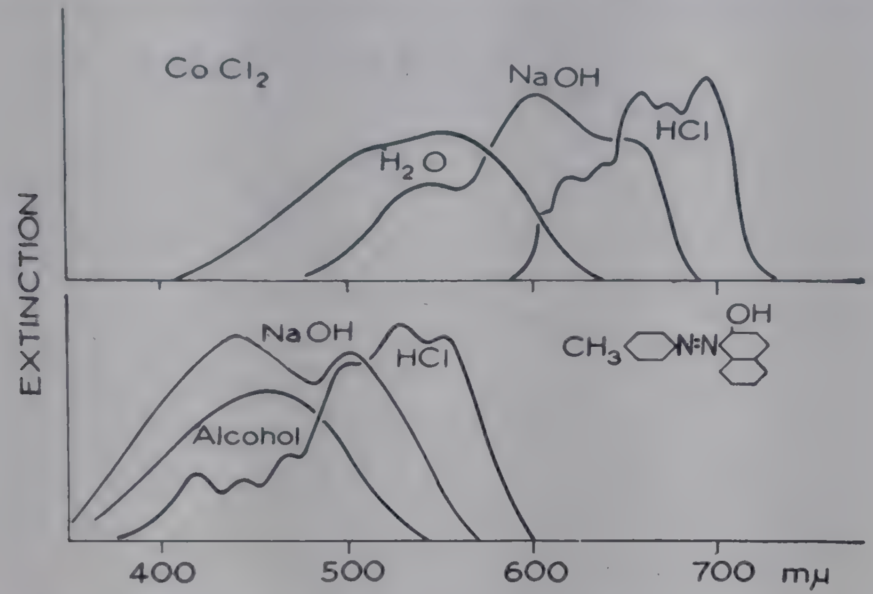


Fig. 9.36. Absorption spectra of compounds with electronically similar chromophores (Brode).

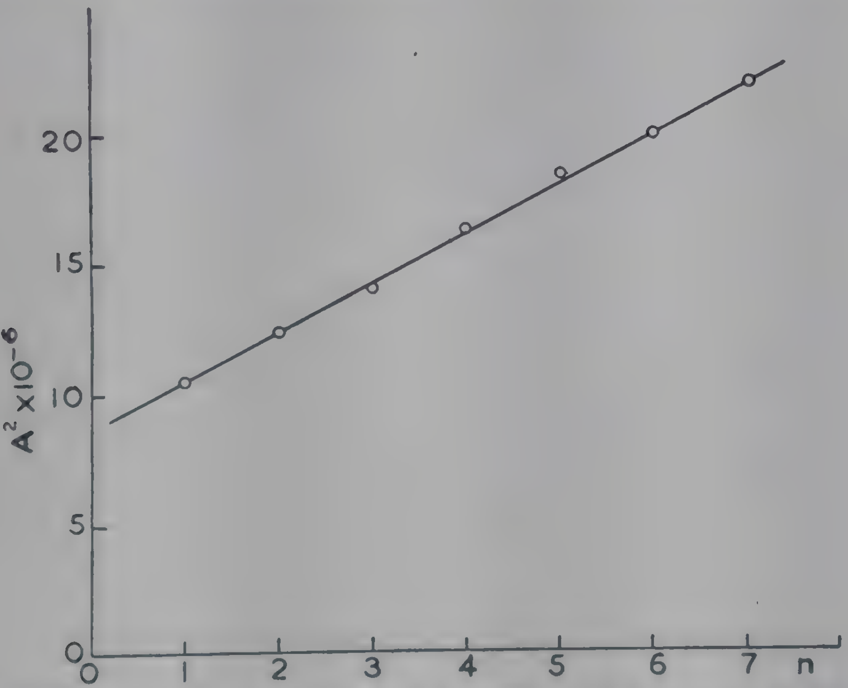


Fig. 9.37. Linear relation between λ^2 and a number of ethenylene linkages in the diphenylpolyene series. (See Fig. 8.31.) (Lewis and Calvin [*C123*].)

If, however, A and B differ in basicity, there is no longer a linear relation between n and λ. As n increases, the mean values of the A-A and B-B bands become increasingly greater than the observed value of the A-B band. Such deviations from a linear wavelength shift with respect to the number of (—CH═CH—) groups approach a linear relation with the square of the wavelength in the series of diphenylpolyenes (Fig. 9.37) (*B5*).

An offset of $(2350)^2$A in the ordinate corresponds to the theoretical wavelength of the basic or parent resonator. By reducing various series of polyethenylenic band frequencies to equivalent values Hausser has shown that some seventy of such compounds conform to the same curve (Fig. 8.31) when plotted on a frequency/ethenylene basis. It was also pointed out that the intensity of absorption was also a function of the number of ethenylene groups. Lewis and Calvin (*C123*) have shown that for such resonators as the diphenylpolyene type (C_6H_5—$(CH{=}CH)_n$—C_6H_5) the value n may be expressed as

$$n = \frac{\lambda^2}{k}$$

in which k is a constant involving the effective mass and restoring forces and in the Fig. 9.37 is equivalent to the offset value of 235 mμ.

The linear relations with respect to frequency (ν), wavelength (λ), or square of wavelength (λ^2) and certain properties of the absorption band are not incompatible with theories of a simple harmonic vibration.

The nature of absorption bands is such as to preclude the possibility of observing in solution form the separate effects due to either rotational or vibrational bands as superimposed on electronic bands. In many cases electronic bands overlap each other so as to make it difficult to resolve them as separate effects. With increased molecular complexity and the accompanying pyramiding of spectral effects on each other there appears in many chromogens, however, a simplification in spectra which may be interpreted as a molecular vibration or resonance. This molecular vibration involves molecular aggregates which are much larger in size than those considered in simple molecular band spectra and hence deviate from the simpler type of band spectra. The more complicated resonators often produce sharp and well-defined spectra (chlorophyll, hemoglobin, and organic dyes [Figs. 9.18, 9.19, 9.20, and 9.29]) which may be resolved into what appears to be a simple series of harmonic absorption bands at equal frequency intervals (*C93, C17*).

In general a resonating structure, either ionic or neutral, may be considered to have a complete electron shell as a protecting surface to the resonator, and within this shell there is a deficiency of electrons which permits electron level transitions, and hence resonance occurs. The rare earths have an incomplete electron shell (4 *f* electrons in the *N* shell) with a complete octet *O* shell surrounding this incomplete shell and a completed *P* shell formed by the 2 *s* electrons combined with covalent bonding of attached anions. With the protection of these outer layers and atoms, it is to be expected that the resonance will follow definite transitions from vibration, rotation, and electronic levels with a resulting sharp, almost line-like absorption spectrum (Fig. 9.4).

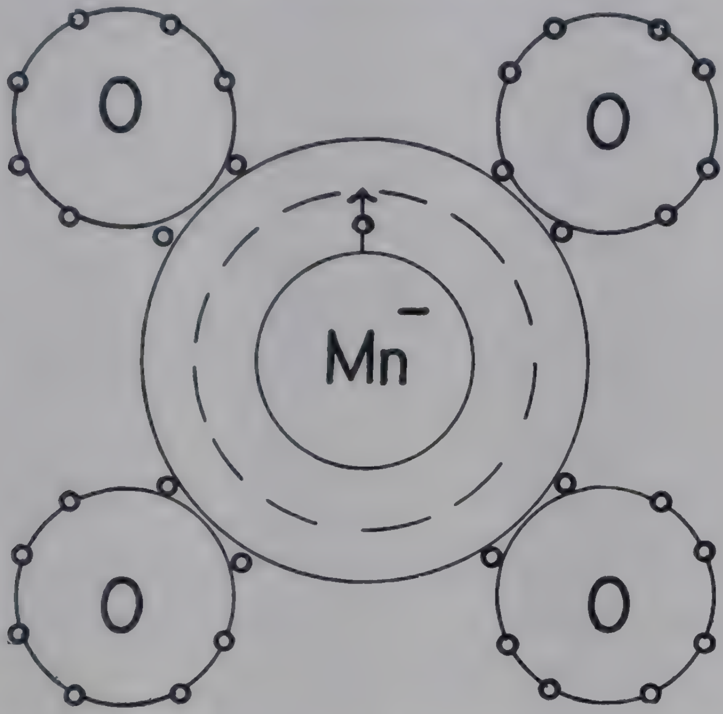


FIG. 9.38. Diagrammatic representation of electron shift in absorption in the permanganate ion. (Note incomplete electron shell [dotted] with protecting outer shell [solid] formed with shared electrons from the oxygen atoms.) (Brode [*C29*].)

Polyatomic ions and molecules involving covalent linkage may result in protecting layers being applied to electron-deficient shells so as to produce well-defined transitions. Examples of such are found in the manganate ion (Figs. 8.6 and 9.38), in which the oxygen layer forms this protecting shell to shield the transition layers from outside effects. The absorption spectrum of the permanganate ion has a well-defined structure with some seven components in the principal band. A similar protection is offered by the halogen atoms surrounding the cobalt atom in the complex $CoCl_4^{--}$, and, as would be expected, the protecting layer of halogen atoms, especially in a halogen acid solvent so as to produce an excess of similar halogen ions, the absorption spectrum shows a distinct structure with sharp bands approaching the rare-earth spectra in characteristics.

The concept of incomplete levels, layers, or shells with a completed outer protecting layer can be applied to organic polyatomic resonators

(Fig. 9.39) in which the resonating structure or chromophore may be considered to be protected by an electron layer involving eight or more electrons. By insulation of this resonator by nonresonance transmitting atoms (Fig. 9.35), or the use of solvents of an insulating nature (Fig. 8.3) or lowering the temperature so as to reduce the effects of adjacent molecules (Fig. 7.50), it is possible to resolve or concentrate the transition into definite energy values with a resulting resolution of the absorption bands into nearly line-like components.

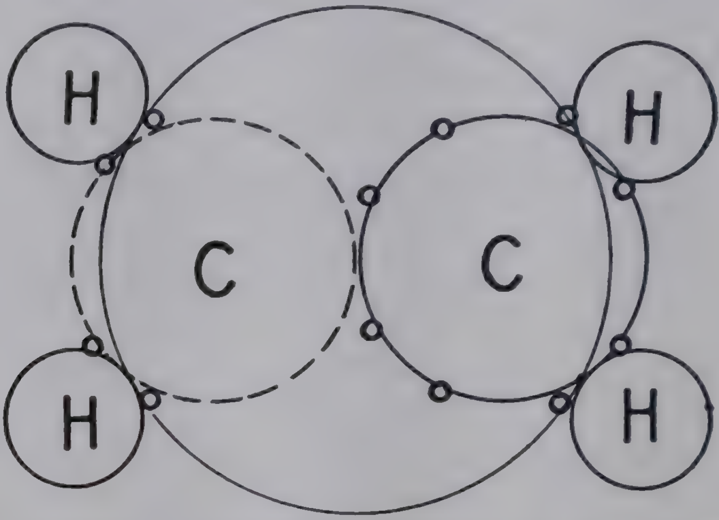


FIG. 9.39. Quantitative representation of electron structure in one of the resonating states of ethylene. (Note complete octet [outer circle] with complete and incomplete carbon shells within.)

LITERATURE

General

H. LEY, "Beziehungen zwischen Absorption und chemischer Konstitution" (*B47*).
G. SCHEIBE, "Molekulspektren von Lösungen und Flüssigkeiten" (*B70*).
P. RAMART-LUCAS, "Structure des molécules et spectres d'absorption" (*B67*).
R. A. MORTON, "Absorption Spectra of Vitamins and Hormones" (*B60*).
E. S. MILLER, "Quantitative Biological Spectroscopy" (*B57*).
F. F. HEYROTH, C. ELLIS, and A. A. WELLS, "The Chemical Action of Ultraviolet Rays" (*B16*).
I. LIFSCHITZ, "Spektroskopie und Kolorimetrie" (*B49*).
J. MARTINET, "Coleur et constitution chimique" (*B54*).
J. R. LOOFBOUROW, "Borderland Problems in Biology and Physics" (*C127*).
G. N. LEWIS and M. CALVIN, "The Color of Organic Substances" (*C123*).
G. E. K. BRANCH and M. CALVIN, "The Theory of Organic Chemistry" (*B5*).
W. R. BRODE, "Absorption Spectra as Applied to Molecular Identification and Analysis" (*C29*).

Reference

HENRI (*B29*), SCHUMM (*B71*), MORTON (*B61*), BRODE and LEERMAKERS (*B8*) BRODE (*B7*), CARR and SHERRILL (*B9*), HEILMEYER (*B27*), SKLAR (*C183*).

CHAPTER X

INFRARED AND RAMAN SPECTRA

INFRARED SPECTRA

It has been necessary to limit the spectral region which was covered in the preceding chapters, and hence no discussion of infrared and Raman spectra was included. In the clasification of atomic and molecular energy it has been pointed out that one could consider the total energy as the sum of the electronic, rotational, and vibrational energies. (page 144).

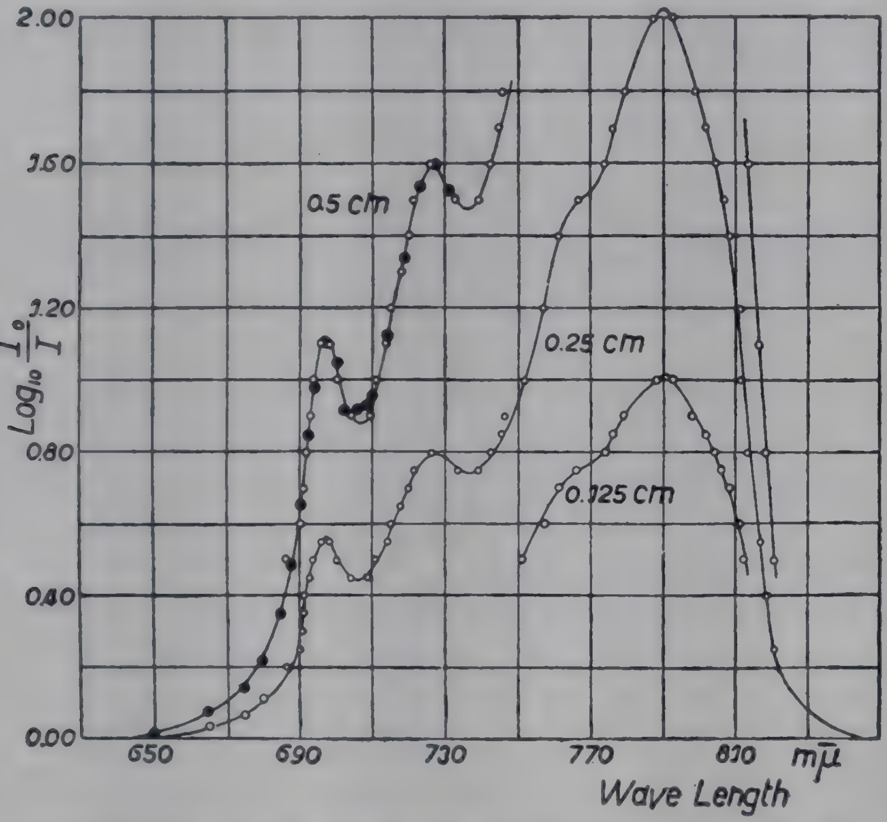


FIG. 10.1. Absorption of cobalt iodide in concentrated hydriodic acid. 1.77 grams $CoI_2 \cdot 6H_2O$ per liter; cell thickness, 0.125 and 0.5 cm (center curve obtained from the other two). ● = visual, ○ = photographic. (Brode and Morton [*C47*].)

$$E = E_r + E_v + E_e$$

In this classification, bands produced by systems in which there is a change in electronic energy are known as electronic bands and are located in the visible and ultraviolet. Occasionally they may extend into the near infrared (CoI_2) (Fig. 10.1). If ν_e (frequency change due to electronic bands) is equal to zero, then the bands are the result of vibrational-rotational effects and are usually called vibration bands (i.e., $\nu_e = 0$; $\nu_r = 0$). Such bands, owing to their low energy, occur in the infrared and seldom in the near (photographically available) infrared.

If $\nu_v = 0$, as well as $\nu_e = 0$, the only energy change will be that of rotation and the bands produced will be known as rotation bands. These bands, owing to the very small energy change involved, will occur in the far infrared (in the neighborhood of 100 μ). The pure rotation spectrum is distinctly separated from the vibration spectrum, which appears between 1 and 23 μ, so that there are three distinct spectral regions of molecular absorption and emission spectra.

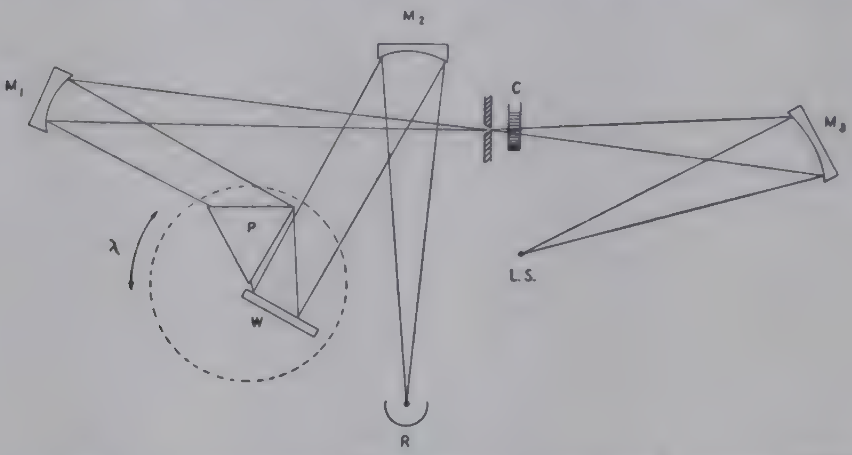


FIG. 10.2 Infrared spectrometer, Wadsworth mounted prism (*P.W.*), concave focusing mirrors (M_1, M_2, and M_3), light source (*L S*) (Nernst glower), thermopile (*R*), and sample (*C*), in front of the spectrometer slit.

Our discussion so far has dealt with the electronic type of molecular spectra. The two remaining fields of spectra are not only separated in their spectral regions but also require a somewhat different technique for study. In the vibration band region, 1–23 μ, one can use a prism spectrometer of suitable transmission properties, such as rock salt, quartz, fluorite, or sylvite, or a grating, for dispersion, and can record the spectra by means of a thermopile or other infrared-sensitive device (Fig. 10.2). The most suitable source of radiation is a Nernst glower.

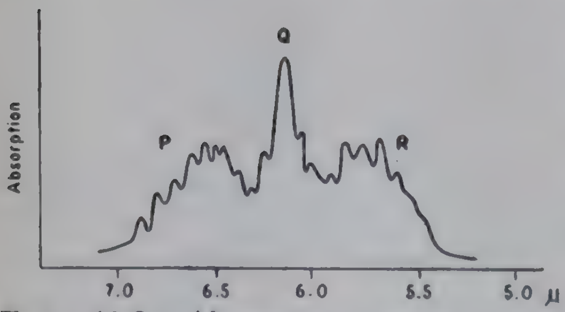


FIG. 10.3. Absorption spectrum of NH_3 (Robertson and Fox [*C169*]).

As in the case of the electronic spectra, simple molecules in a vapor state produce spectra with a resolvable fine structure in which the *P*, *Q*, or *R* branches are easily identified. (The *Q* branch will appear only if there is an allowed vibration change with no rotation change [Fig. 10.3].)

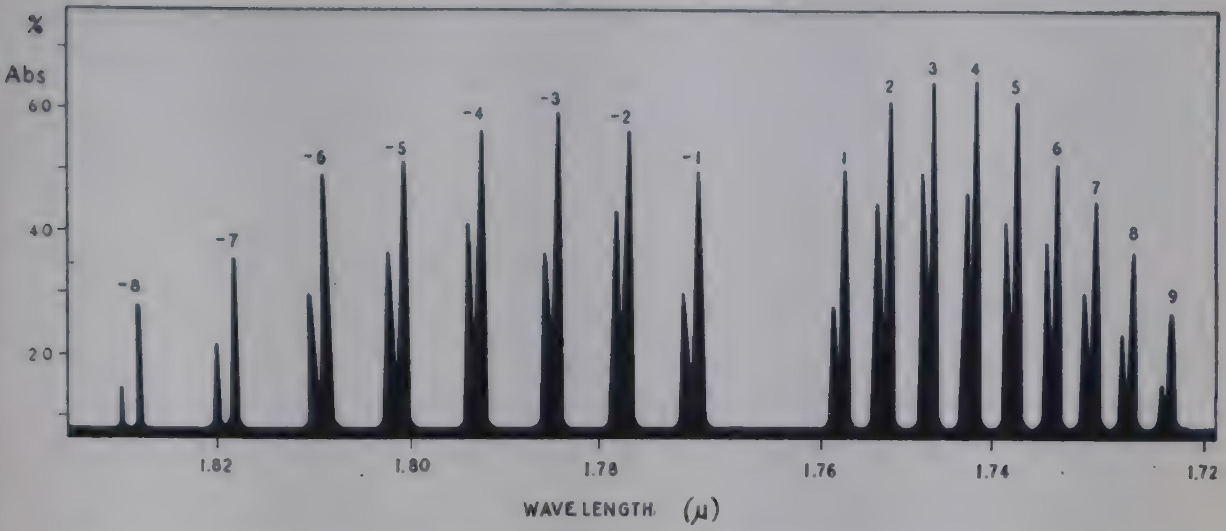


FIG. 10.4. Isotope effect in the 1.76 μ band of HCl (first harmonic of the fundamental 3.4 μ band) showing P branch to left of center and R branch to right of center (Meyer and Levin [*C142*]).

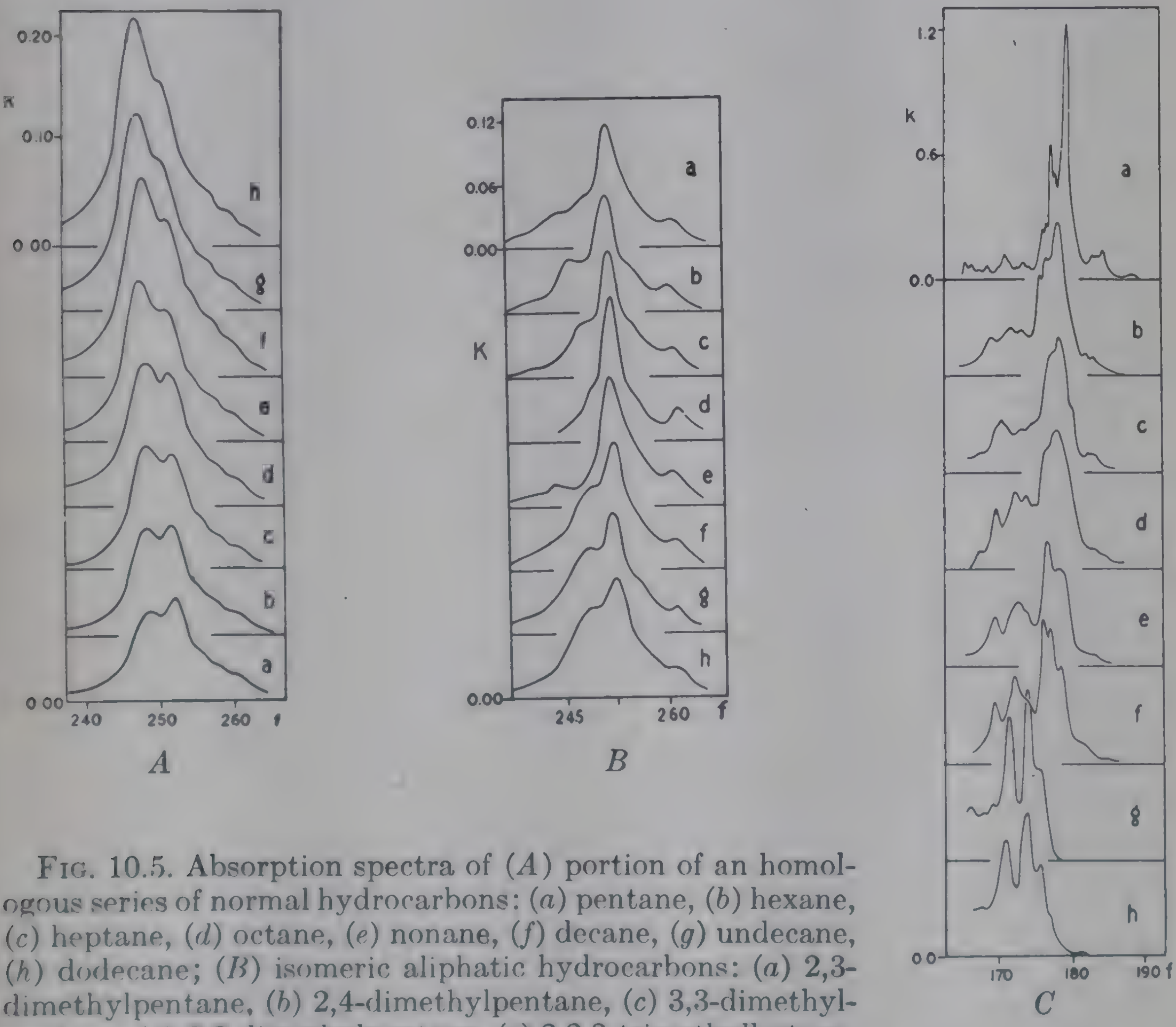
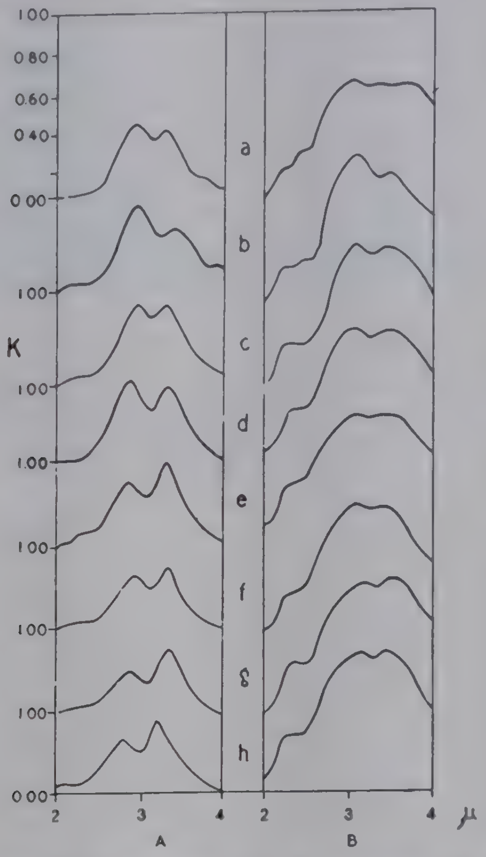


FIG. 10.5. Absorption spectra of (*A*) portion of an homologous series of normal hydrocarbons: (*a*) pentane, (*b*) hexane, (*c*) heptane, (*d*) octane, (*e*) nonane, (*f*) decane, (*g*) undecane, (*h*) dodecane; (*B*) isomeric aliphatic hydrocarbons: (*a*) 2,3-dimethylpentane, (*b*) 2,4-dimethylpentane, (*c*) 3,3-dimethylpentane, (*d*) 2,2-dimethylpentane, (*e*) 2,2,3-trimethylbutane, (*f*) 3-ethylpentane, (*g*) 3-methylhexane, (*h*) 2-methylhexane; and (*C*) aromatic hydrocarbons: (*a*) benzene, (*b*) toluene, (*c*) ethylbenzene, (*d*) *o*-xylene, (*e*) *m*-xylene, (*f*) *p*-xylene, (*g*) cyclohexane, (*h*) methylcyclohexane. (Liddel and Kasper [*C125*].)

The production of rotation bands is possible only in polar molecules that possess an electric moment when at rest; hence symmetrical molecules such as chlorine would not be expected to show such bands. Most of the work that has been done in infrared spectroscopy has been in the region of 1 to 20 μ on what we have termed the rotation-vibration spectra, more commonly known as the vibration spectra.



a. Methyl alcohol
b. Ethyl alcohol
c. Propyl alcohol
d. Butyl alcohol
e. Amyl alcohol
f. Hexyl alcohol
g. Heptyl alcohol
h. Octyl alcohol

FIG. 10.6. Absorption spectra of a portion of an homologous series of alcohols, (*A*) solution in CCl_4, (*B*) liquid (Ellis [*C79*]).

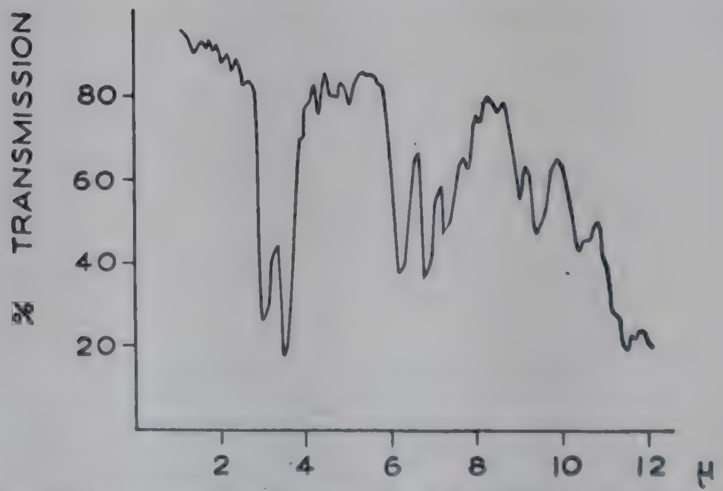


FIG. 10.7. Absorption spectrum of *n*-butylamine (Bell [*C10*]).

By means of reasonably good resolution it has been possible to show, in the 1.76-μ band of hydrochloric acid (first harmonic of the 3.4-μ band), a doublet structure indicating the relative amounts of Cl^{35} and Cl^{37} as isotopes in the HCl gas (Fig. 10.4) (*C141*). Since an electrical moment is required to show rotational structure it is possible to apply the study of band spectra to such compounds as carbon dioxide to determine the

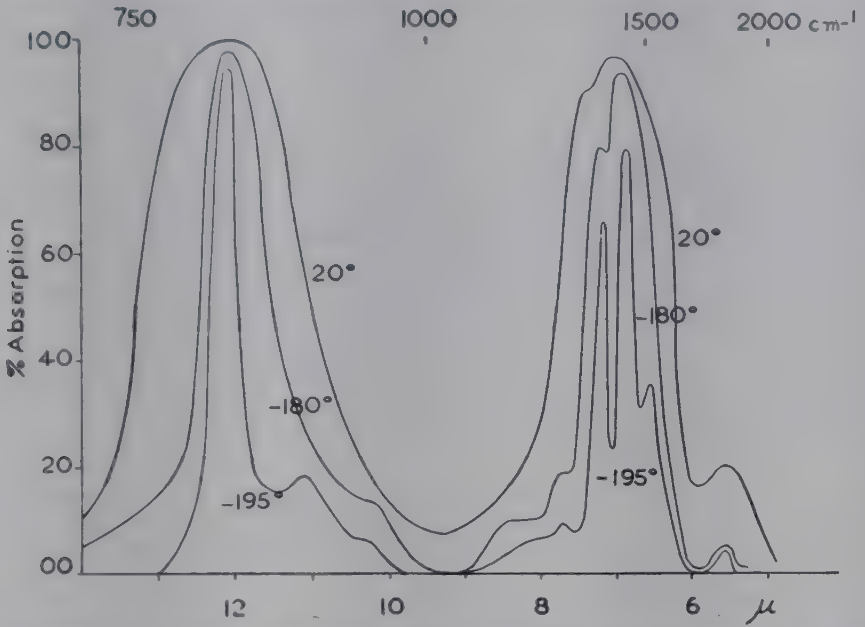


FIG. 10.8. Influence of temperature on the resolution of infrared absorption spectra (Avery and Ellis [*C4*].)

vibrational and angular conditions in the molecule. The vibration spectra can thus be applied to the coupling between ions or atoms as differentiated from electronic spectra, involving transitions of electrons.

TABLE 10.1

FREQUENCY VALUES FOR INFRARED ABSORPTION BANDS DUE TO THE INDICATED LINKAGES

Functional Group	Frequency (Wavenumber ν′)	Functional Group	Frequency (Wavenumber ν′)
≡C—H	2910 cm⁻¹	—S—H	2500
≡C—C≡	990	=N—H	3300
=C=C=	1630	≡C—I	500
—C≡C—	2200	≡C—B	560
=C=O (*ketones*)	1722	≡C—Cl	650
=C=O (*acid*)	1660	—C≡N	2250
≡C—N=	1035	—N≡C	2150
≡C—O—	1034	=N—O—	1003
—O—H	3380	—NH—NH—	3000

In the field of liquids one finds a broadening of the absorption bands as was observed in the electronic spectra (visible and ultraviolet) (Figs. 10.5 and 10.6). From the data that have been obtained it has been possible to assign frequency or wavelength values to simple vibration linkages such as C—C, C—H, C—N, O—H, and to show that in homologous series intensity rather than frequency differences usually are found in the absorption bands (Fig. 10.6). A considerable amount of data has been collected by Coblentz (*D7*), Bell (*C10*), Ellis (*C79*) and others (Fig. 10.7) on the absorption spectra of organic and inorganic compounds, from which one can obtain characteristic spectral frequencies for many functional groups (Table 10.1). Since this field of spectral analysis was not contemplated as a portion of the radiant-energy effects to be discussed in this book those interested in the application and methods should consult the references given at the end of this chapter, (Fig. 10.8).

RAMAN SPECTRA (*B33*)

Raman discovered in 1928 the phenomenon which is called the Raman effect (*B38*, *B42*) and which results from the scattering of light by a substance (usually a liquid, although solids and gases have been investigated). When a substance is illuminated by a monochromatic radiation, the molecules for the most part will transmit this radiation unabsorbed, i.e., if they absorb and give up the same light frequency they would become a point source and the light would appear to radiate from the solution. To the degree that the molecules or particles in the solution absorb the energy and then re-emit it we speak of scattering of the light, and for colloidal particles the phenomenon is known as the Tyndall effect. Such an effect enables us to observe the location and motion of particles which exceed the normal limits of microscopic examination.

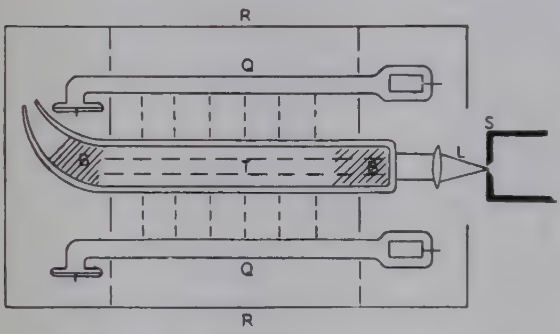


FIG. 10.9. Apparatus for production of Raman spectra; tube for compound (*T*); mercury lamps (*Q*); reflecting box (*R*); spectrograph slit (*S*). The ends of the tube are usually blackened (*B*) to reduce direct illumination of the slit.

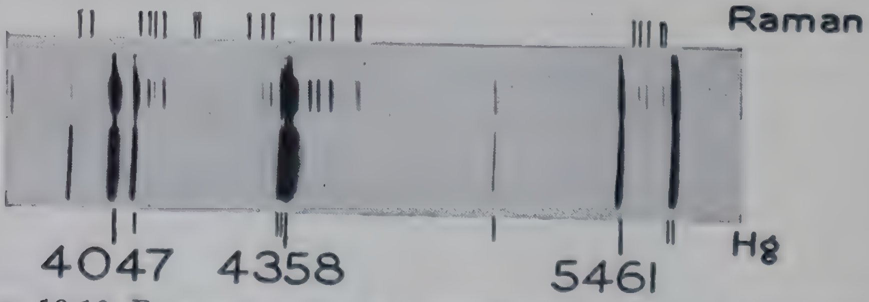


FIG. 10.10. Raman spectrum of carbon tetrachloride (Jeppeson).

The important contribution that Raman made was the observation that this scattered light from a monochromatic illumination was not all of the same frequency as the incident beam. If ν_i represents the frequency of the incident radiation and ν_s the frequency of the scattered light, then one may represent the energy of these two rays as $h\nu_i$ and $h\nu_s$, and the energy difference between the two rays as $h\ (\nu_i - \nu_s)$, where $(\nu_i - \nu_s) = \Delta\nu$, or the Raman frequency. In general, $\Delta\nu$ is positive, although the theory of formation permits negative values, and such values have been observed.

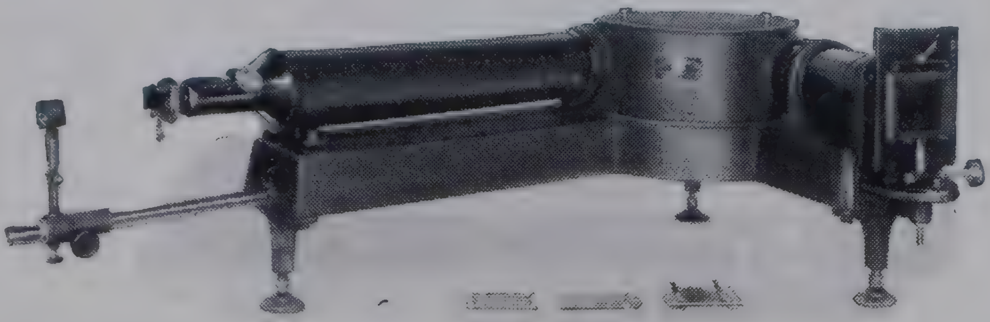


FIG. 10.11. Large-aperture spectrograph for Raman spectrum observation (Gaertner).

The frequency differences produced in the Raman spectrum are quite definite and are evidently due to quantized conditions. The usual differences are of the order of 15 to 250 f, which would correspond to the wavelength region of radiation from 20.0 to 1.2 μ or the region of vibration-rotation band spectra. It can be shown that these observed frequency shifts are identical with the frequency intervals in the vibration band spectrum, and hence it is possible to observe these infrared values within the photographic radiation range. The usual method of observation is to illuminate a tube containing the liquid with a powerful discontinuous source such as a battery of mercury lamps and observe the scattered light from a flat end of the tube (Fig. 10.9).

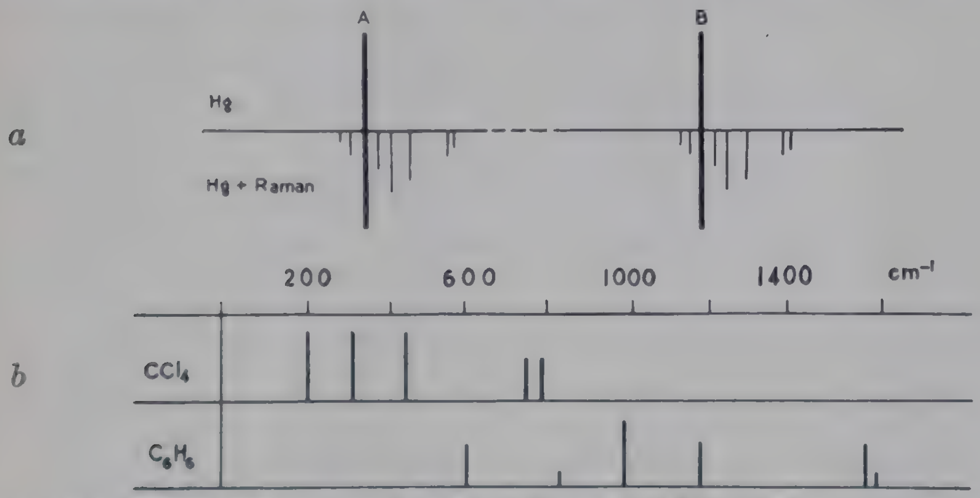


FIG. 10.12. Raman spectrum analysis (length of line indicates intensity).
a. As observed in photograph (heavy lines *A* and *B* indicate exciting source).
b. Frequency analysis.

Raman spectrum determinations can be made with ease on the apparatus available to the analyst who is equipped to do the usual types of absorption and emission determinations described in the previous chapters, and for this reason it may be worth while to indicate in more detail the type of results which can be obtained. The Raman spectrum, like the vibration spectrum in the infrared, indicates resonance relations between linkages, and, as with the vibration spectrum, it is possible to assign certain frequency values to represent the resonance or vibration of certain linkages. In the simple inorganic compounds there is not much necessity to determine the presence or absence of certain linkages since the structure of most of the compounds is definitely known. In the field of organic chemistry, however, where a large number of isomeric compounds are possible it has been found useful to know the kind of linkages present in the compounds.

The characteristic frequency or displacement of the C—H linkage is about 90 f (2930 cm^{-1}) (equivalent to a position in the infrared of 3.41 μ). As can be seen from Table 10.2, the shift is not a constant one but is influenced by the other linkages in the molecule. The effect of these perturbations, however, is not great enough to prevent the identification of the group or bond producing the shift. The figures in Table 10.3 representing the frequency shifts are average values which are influenced by other linkages in the molecules. Raman band positions (intensities indicated by height) are usually published in the manner shown in Fig. 10.12*b*.

TABLE 10.2

RAMAN SHIFTS FOR C—H LINKAGE

C—H aliphatic average.....	2918 cm^{-1}	C—H primary aliphatic....	2862–2930
C—H aromatic average....	3054	C—H secondary aliphatic...	2970

There is a very close relationship between Raman spectra, absorption spectra, and fluorescence (see Chapter XI). In all three of these phenomena, light is absorbed and the energy is re-emitted. If the energy is re-emitted in the form of heat, the effect is known as an absorption spectrum. If the spectral energy is re-emitted in the form of light, the effect is known as fluorescence. If the fluorescent light is of a wavelength greater than the exciting wavelength, the effect is normal If the wavelength of the fluorescent light is less than the exciting light, an anti-Stokes effect is produced. If the wavelength of the emitted light is the same as the exciting light the effect is known as resonance fluorescence.

TABLE 10.3

RAMAN SHIFTS FOR CHARACTERISTIC LINKAGES

Linkage	cm^{-1}	Linkage	cm^{-1}
C—H aliphatic	2800–2970	S—H	2570
C—H aromatic	3054	C—S	645
C—C aliphatic	800–1000	N═O nitrate	1640
C—C aromatic	1580–1608	nitrite	1640
C═C	1600–1650	nitro	1565
C≡C	2100–2250	C═N	1650
C—OH	820–880	C≡N	2150
C═O acid	1700	C—N nitro	910–930
ketone	1710	amine	880
aldehyde	1720	N—O	1000–1080
ester	1720	C—Cl	650–710
anhydride	1770	C—Br	570–600
O—H	3400	C—I	500–530

In the Raman spectrum the relation between the wavelength of the exciting light and the re-emitted light bears a definite relation to the vibration and rotation effect of the atoms within the molecule.

LITERATURE

General

J. LECOMTE, "Spectres dans l'infra-rouge" (*B42*).

F. I. G. RAWLINS and A. M. TAYLOR, "Infrared Analysis of Molecular Structure" (*A78*).

K. W. F. KOHLRAUSCH, "Der Smekal-Raman-Effect" (*B38*).

J. H. HIBBEN, "The Raman Effect and Its Chemical Applications" (*B33*).

Reference

BOURGEL and PIAUX (*B4*), LECOMTE (*B41*), PRINGSHEIM (*65*), TELLER (*74*).

CHAPTER XI

COLORIMETRY AND FLUORIMETRY

Definition of Color

It is with some feeling of uncertainty and perplexity that one approaches the general subject of color and colorimetry. This feeling is caused largely by the inability of the physicist, the psychologist, the artist, and other interested persons to agree upon any common system of nomenclature for the physical description of color. Such expressions as color, brightness, hue, brilliance, intensity, purity, transmission, and level have no exact definition, and one finds some difficulty in the exact description of color terms. The sensitivity of the eye to various colors in the spectrum varies, as is indicated by the visibility curve of the eye (*C91*) (Fig. 11.1). The maximum sensitivity is at about 555 mμ, and the limits are about 400 and 750 mμ. This visual spectrum produces in the eye the stimulus of color sensation with spectral colors usually classified as follows:

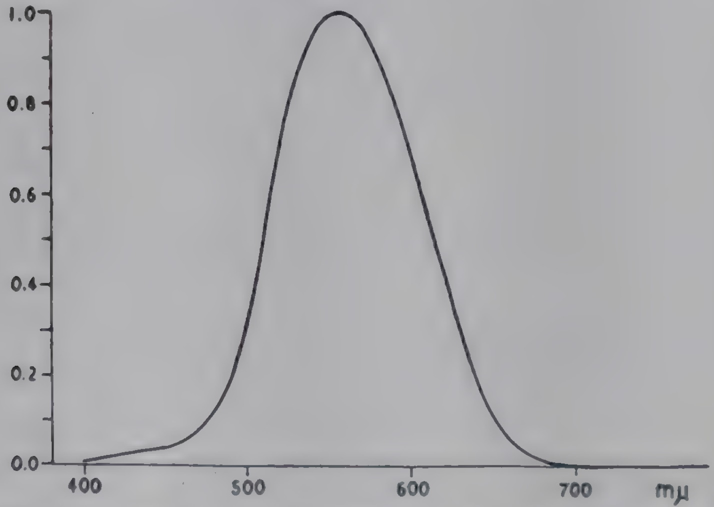


Fig. 11.1. Visibility curve. Relative brightness of equal spectral energy (*D7*).

Red	750–620 mμ
Orange	620–590 mμ
Yellow	590–570 mμ
Green	570–500 mμ
Blue	500–450 mμ
Violet	450–400 mμ

By purity of color one usually means the approach to monochromatic character in the color of the emitted, transmitted, or reflected light, or, in terms of a transmission spectrum, the narrowness of the transmission band. Color, as we generally recognize it, is the result of absorption, either by transmission of light through the sample or reflection from the sample. Reflection is a form of absorption in which certain portions of the spectrum are absorbed and the remainder are reflected. For example, a piece of colored Cellophane when held up to a light will transmit a certain portion of the spectrum and absorb the remainder. If the same piece is placed on a mirror surface and light is allowed to fall on it and to reflect back, one has a reflection spectrum which will correspond to the absorption spectrum.

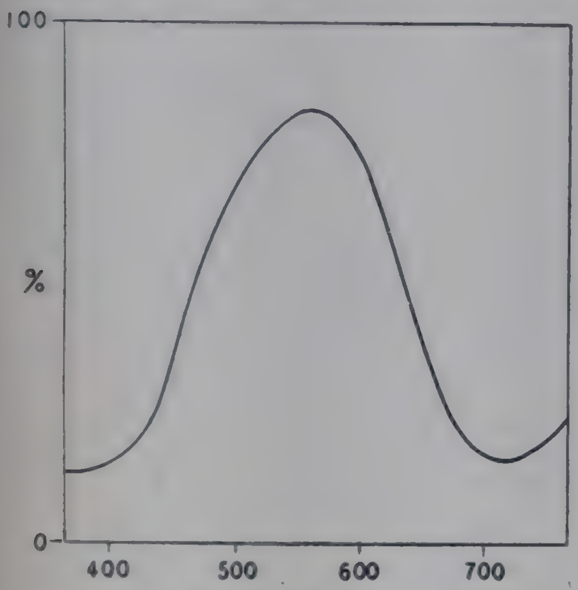


Fig. 11.2

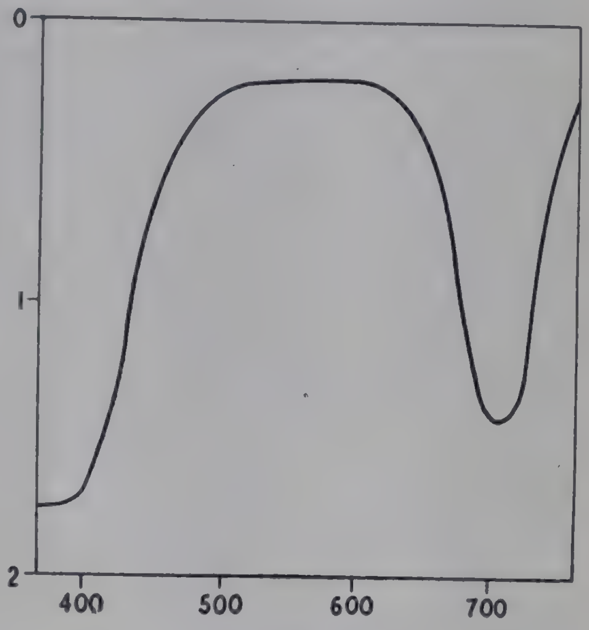


Fig. 11.3

FIG. 11.2. Transmission curve of green sample.
FIG. 11.3. Extinction curve (plotted downwards) of green sample used in Fig. 11.2.

It should be borne in mind that color, as one sees it with the eye, as a result of a colored filter or piece of paper, represents the light which is transmitted or reflected rather than that which is absorbed.

In our previous discussion we have dealt with light which was absorbed and with the measurement of absorption spectra, transmitted light being the complement of the absorbed light. Transmission (T) thus may be defined as equivalent to 1 − absorption (A), or

$$T = 1 - A$$

where $T = I/I_0$, or the portion of light transmitted, and $A = \frac{I_0 - I}{I_0}$, or the portion of light absorbed (these values × 100 = the percentage of light transmitted or absorbed). In the "Handbook of Colorimetry" by Hardy (*B26*), use is made of the terms reflection factor and transmission factor; in the "Report on Spectrophotometry" of the Committee of the Optical Society of America (*B21*) the terms absorptivity and transmittancy are used for these values.

Blue color is produced by the absorption of wavelengths other than blue within the visible spectrum. To the chemist who is interested in the structure of the absorbing substance, this absorption region is of importance, and little attention is paid to the transmitted portion of the spectrum. From the standpoint of color production, however, it is the color transmitted which is of importance. The total portion of energy transmitted may be indicated as the area under the transmission curve (Fig. 11.2) as compared with the area above the curve. In the description of color and color values it thus appears that a more satisfactory indication can be made by the use of transmission or reflection in place of extinction (compare Figs. 11.2 and 11.3), although the same general characteristics are indicated in each curve. Transmission accents the portion of the curve at high percentage transmission and reduces the relative changes of the curve at low percentage transmission (see Figs. 7.51 and 7.58).

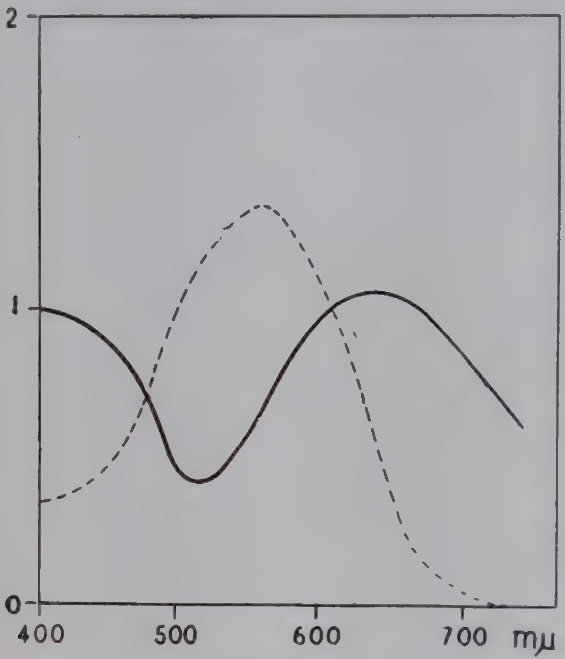


Fig. 11.4. Green sample and its purple complement (dotted).

Color can be described by a curve, and this in turn by a mathematical formula. Such a formula would be too complicated to handle, and so an effort has been made to define color by means of an approximation into three factors—purity, brilliance, and dominant wavelength. Purity, as has been indicated, is a measure of the narrowness of the transmission band, where a single monochromatic line would indicate 100 per cent purity and a flat level transmission (typical of a gray) would represent 0 per cent purity. Brilliance, or brightness, as it is sometimes called, is a representation of the area included in the transmission portion as compared with the absorption portion, i.e., the total percentage of energy or light transmitted. The dominant wavelength is the wavelength of maximum transmission.

TRISTIMULUS VALUES

An analysis of color, as indicated above, would require a standard and uniform shape of all transmission bands, and, since these are irregular, it becomes necessary to define the shape of the curve more exactly. This is done by dividing the visible spectrum into three portions and assigning to each portion a series of values so as to produce curves such as indicated in Fig. 11.5 as $\bar{x}$, $\bar{y}$, and $\bar{z}$. By a series of calculations described by

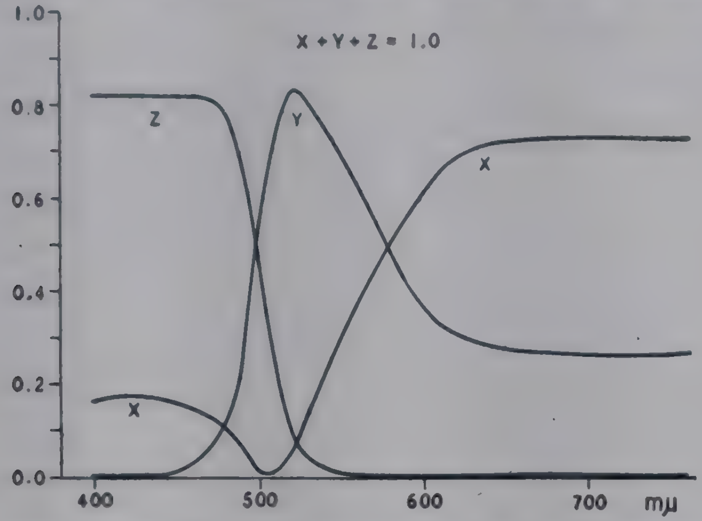


FIG. 11.5. Trichromatic coefficients (proportion of each component in a given wavelength value).

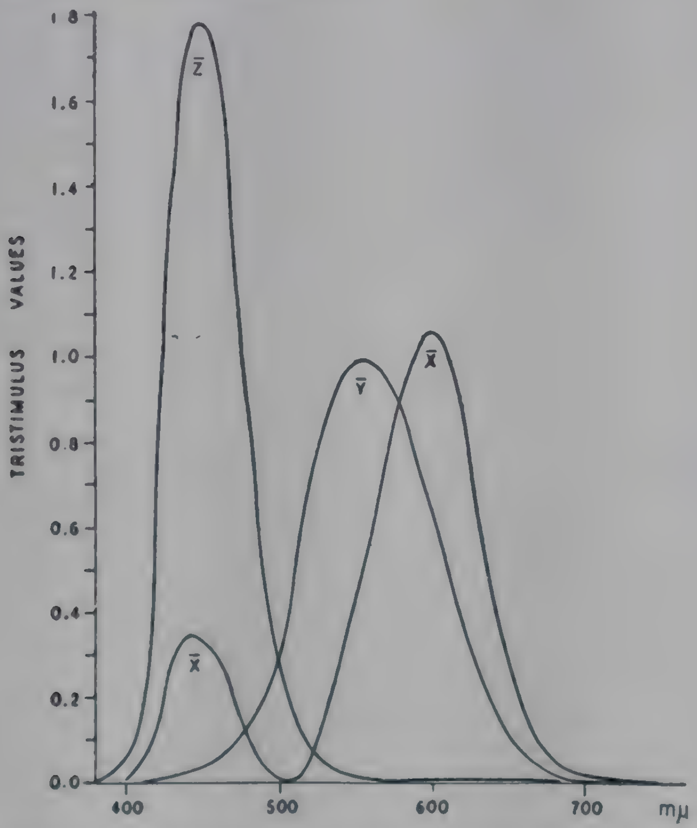


FIG. 11.6. Distribution coefficients for equal energy (tristimulus values).

Hardy it is possible to assign to each unit millimicron a definite coefficient for $\bar{x}$, $\bar{y}$, and $\bar{z}$, and the integration of these values will yield a set of three numbers, X, Y, and Z, representing the color, the brightness, and the purity. In Hardy's system the tristimulus values are arbitrarily chosen so that one of them has two transmission maxima, $\bar{x}$, at 440 and 610 mμ. Other systems designed to indicate color characteristics in terms of a three-number or tristimulus system have been suggested, e.g., the Wright system which takes the wavelengths 650, 530, and 460 mμ as primary standards (*C208*). In the end, the attempts to define colors in terms of three, or even more, primaries become useless when such colors as neodymium pink, tomato red, potassium permanganate, cobalt blue, or chlorophyll green are to be described (Fig. 11.7). Although many colors, especially grays, flat colors, and off shades of white, can be adequately described by this means, it does not suffice for a description of pure chemical compounds for which the absorption, transmission, or reflection spectrum is essential to define the color. In mixtures of compounds where broad smooth curves are obtained, one can apply with sufficient accuracy the tristimulus methods of analysis. Hardy points out that "although the tristimulus values do not provide so much information as the spectrophotometric data, they can be derived from the spectrophotometric data by a straightforward computation procedure. They therefore provide a fundamental basis for a language of color" (*B26*).

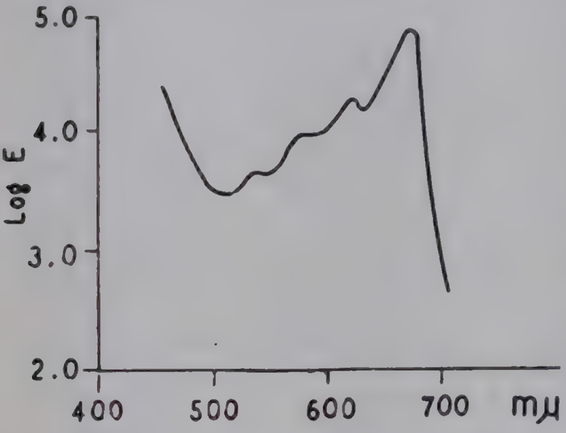
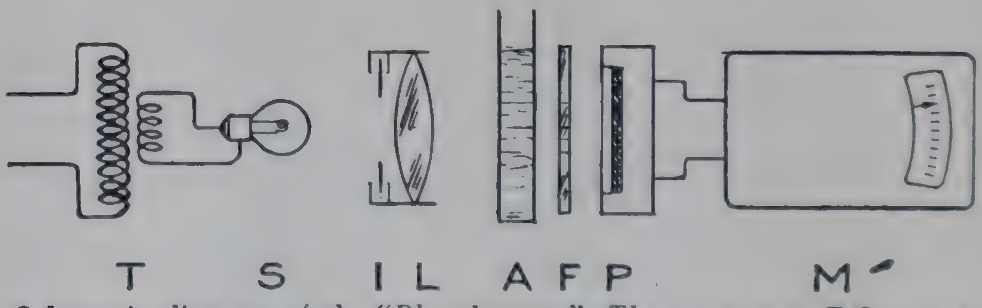


FIG. 11.7. Chlorophyll green (chlorophyll A + B).



Schematic diagram of the "Photelometer". The parts are: T-Constant Wattage Transformer; S-Light Source; I-Iris Diaphragm; L-Lens; A-Absorption Cell; F-Light Filter; P-Photoelectric Cell; and M-Microammeter

FIG. 11.8. Diagram of a photronic colorimeter (Central Scientific Co.).

Colorimetric Applications

With the rapid increase in colorimetric methods of analysis a number of visual and photronic colorimeters have been devised for the measurement of transmission or reflection values of liquids, glasses, and colored papers. Most of these colorimeters are photronic in character, using a copper oxide cell, microammeter, and suitable light source (Figs. 11.8 and 11.9). A series of colored filters are supplied with these instruments so that light intensity may be determined for various wavelengths. The transmission curves are often given for these filters or can easily be determined (Fig. 11.10). As can be seen from the transmission curves,

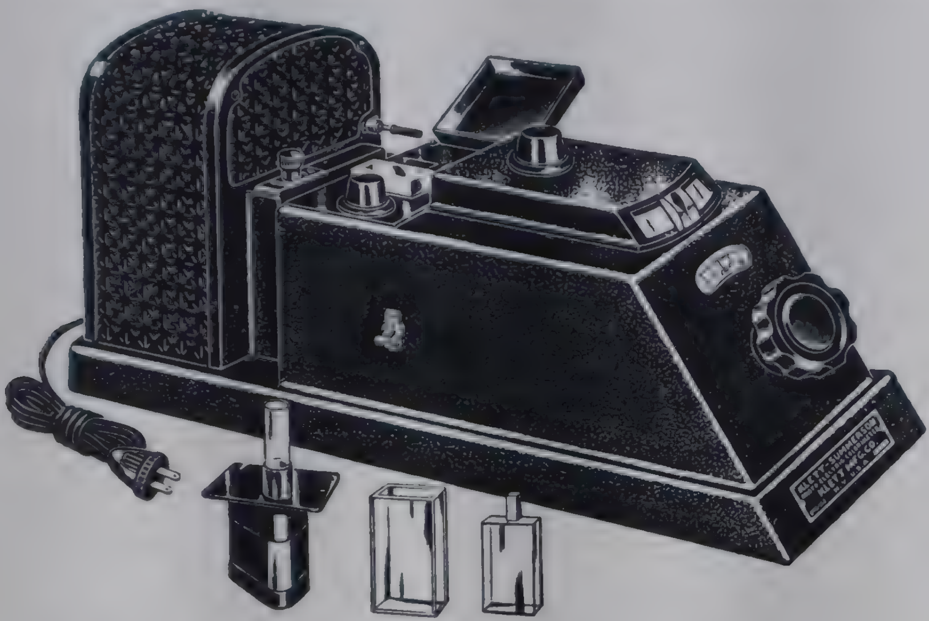


Fig. 11.9*a*. Photronic colorimeter (Klett-Summerson).

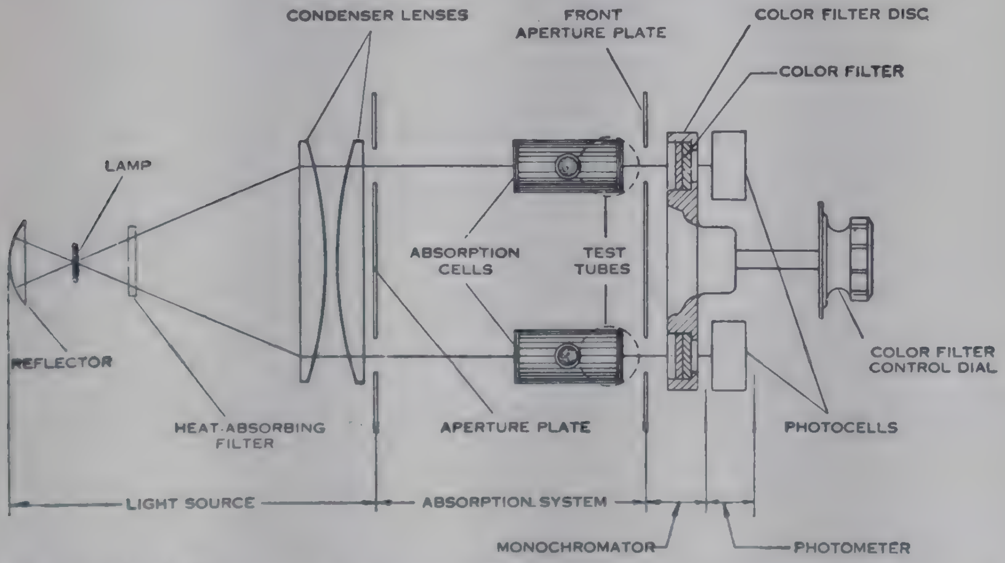


Fig. 11.9*b*. Optical diagram of a two-cell photronic colorimeter (American Instrument Company).

certain of the filters cut off the blue and transmit a portion of the red end of the spectrum; others are the reverse in that they cut off the red end and transmit the blue end, while the green has its highest transmission in the center. A dominant wavelength and a brilliance factor can be assigned to each of these filters, while those which overlap, such as the red and orange, can be separated, i.e., by subtracting from the orange value the observed red value, inasmuch as the orange includes the red and orange spectral region. In a like manner, the yellow contains the yellow orange and red, so that subtraction of the observed orange from the observed yellow will give a true value for the spectral region bounded by the orange and yellow absorption curves. Essentially, this amounts to a series of five rather than three primary components. Additional components could be added by corresponding cut-off systems in the blue and the use of purple filters with both a blue and red transmission.

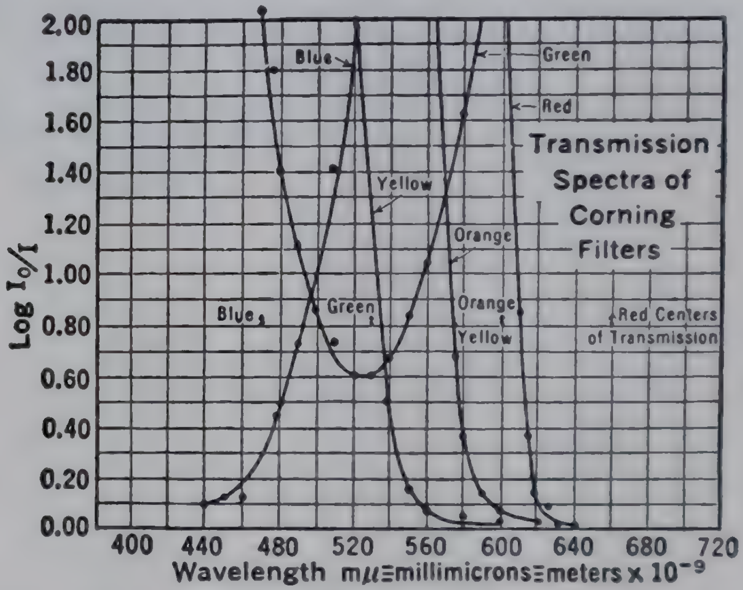


FIG. 11.10. Transmission curves for color filters supplied with M. R. colorimeter (Brode [*C28*]).

In the usual colorimetric analysis it is desirable to determine the amount of colored material in the sample as compared with a standard value. For a blue solution the proper procedure is to use a red filter, since the solution, by virtue of its blue color, is known to transmit blue and absorb red. The amount of material present is measured, not by the amount of light the solution transmits, but by the amount it absorbs, and the most accurate measurements can be made by a spectrophotometric determination at the exact wavelength of its absorption band. A very good first approximation to the use of the absorption band wavelength is to utilize a filter which includes this wavelength and as little of the surrounding spectrum as possible. It is often difficult to convince the observer that one should use a blue filter for a red solution, but a brief experiment will show that a red solution and a clear solution will look alike under a red filter whereas with a blue filter the clear solution will appear clear and blue and the red solution a black or very dark blue.

In our discussion on the theory of the production of absorption spectra we pointed out that the introduction of additional chromophoric or weighting groups produced a hyperchromic and bathochromic effect, by which we meant that the absorption band was intensified and shifted to lower frequency values (i.e., towards the visible). As the absorption band is shifted towards the visible, it first approaches the violet end of the spectrum (Fig. 11.11) and in successive stages can be pushed across the spectrum to reach ultimately the red side and even beyond, so that a second band will begin to appear from the blue side. The successive colors thus produced are as follows:

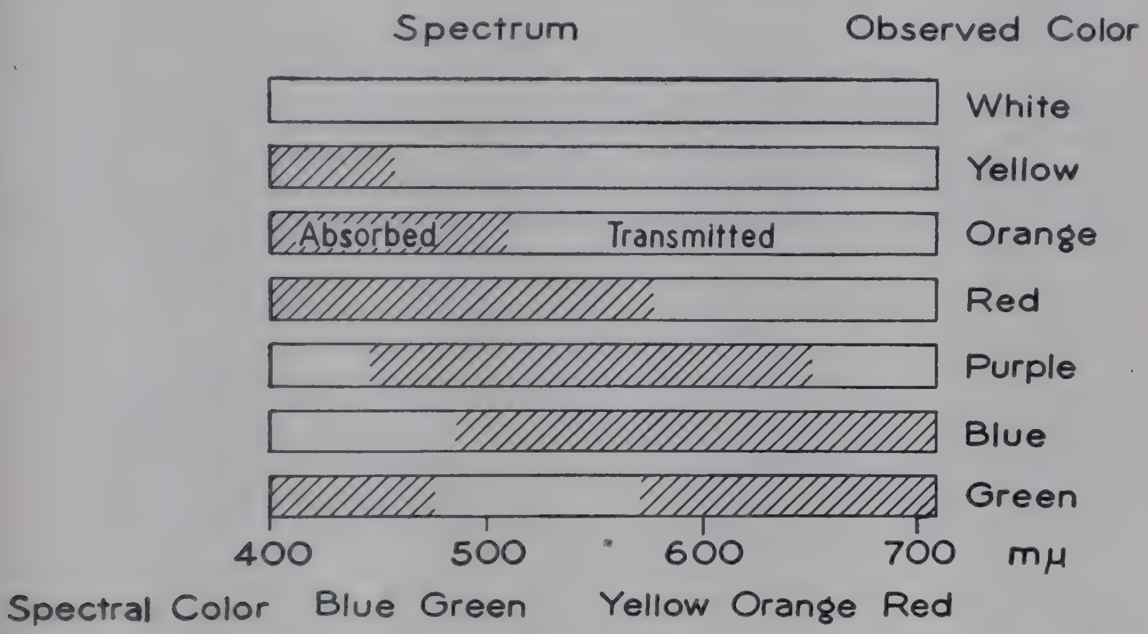


FIG. 11.11. Absorption production of color.

GREENISH YELLOW→YELLOW→ORANGE→RED→PURPLE→BLUE→GREEN

The color of a compound is thus said to be *deepened* if it goes from left to right in this order, i.e., from yellow to purple to green, and, though this is not the true spectral order nor these the true spectral colors, it represents a very important series of color values. In these colors the yellow is not a spectral yellow but includes all the visible spectrum except the blue. In like manner the purple is a combination of two colors, blue and red, rather than a pure spectral color. It would seem, therefore, that color might be better defined on the basis of absorption rather than transmission effects.

It must also be recognized that the psychological definition of color involves other factors such as the response of the eye to environment, change of chromatic response with intensity (Fig. 11.12), and the frequency range of the observed radiant energy.

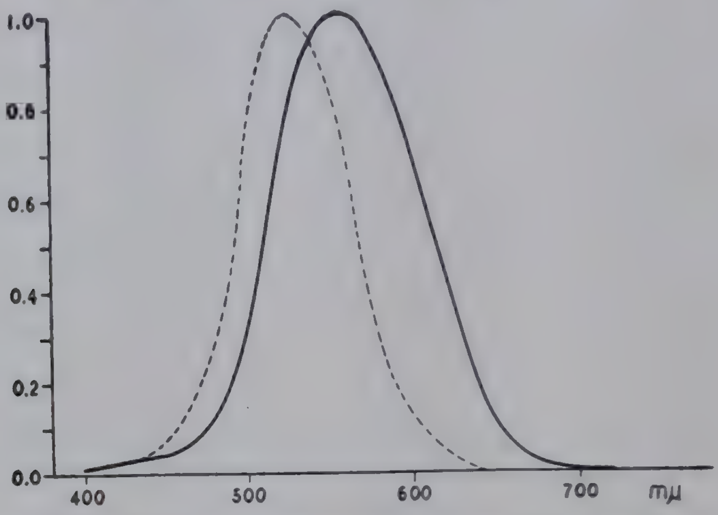


FIG. 11.12. Twilight shift in relative visibility curve (change in chromatic response of the eye to equal intensity). Photopic vision—solid curve, scotopic vision—dotted curve.

FLUORESCENCE

Because of the close connection between fluorescence, phosphorescence, and light absorption, it is in order to discuss the general phenomena of fluorescence and phosphorescence.

Phosphorescence and fluorescence are both forms of photoluminescence in that by excitation of the molecules by light waves they radiate light. Phosphorescence is generally considered to be the effect observed when a compound absorbs light of a given wavelength, and after excitation has ceased, the compound continues to radiate. In the early discussion (see page 144) of the phenomenon of emission and absorption spectra, it was pointed out that absorption spectra result from electrons being forced from their normal levels to higher levels; the return of the electron to its normal level could result in emission spectra, or the electron could, through following transmission levels other than those involved in the absorption, radiate the absorbed energy in the form of heat (infrared or other radiation). In a few cases the transmission levels of the returning electrons are such as to produce light within the visible region of the spectrum and we have the phenomenon known as phosphorescence or fluorescence. It is also true that the application of energy other than light, such as that from chemical reactions, may result in this same type of electron transition, producing visible light, and such reactions are known as chemiluminescence.

The difference between phosphorescence and fluorescence is merely a matter of the lag of the rate of re-emission of light after the exciting light has been removed, fluorescence ceasing upon the removal of the exciting light or agent and phosphorescence continuing. Phosphorescent compounds eventually lose their luminosity and must be again exposed to ultraviolet, x-ray, visible light, or other exciting source in order to activate the phosphors. The incorporation of radioactive substances with phosphorescent substances will provide an invisible exciting source incorporated with the phosphorescent material so as to produce continuous radiation of light. It has been demonstrated that reducing the temperature of a phosphorescent material with liquid air retards the phosphorescent effect and that warming the compound to room temperature results in its return to normal phosphorescent rate and that heat or exposure to infrared results in an accelerated phosphorescence with a shorter period of radiation.

Many inorganic and organic substances show fluorescence. Two of the common examples of such substances are uranium glasses and the dye fluorescein. The dye gives an orange-red solution when viewed by transmitted light but by reflected light gives a brilliant green due to its fluorescence. The color produced by fluorescence and the wavelength region of the light which produces fluorescence are characteristic properties of the different fluorescing compounds.

According to Stokes' law the emitted light should have a longer wavelength than the exciting light. Although Stokes' law is generally applicable, there are a few cases of anti-Stokes effects involving the emission of shorter wavelengths than that of the exciting line. Of particular interest in the field of fluorescence are the effects produced by irradiation with ultraviolet light so as to produce visible fluorescence. It is obvious that the nature of the physical state of compounds will have a marked

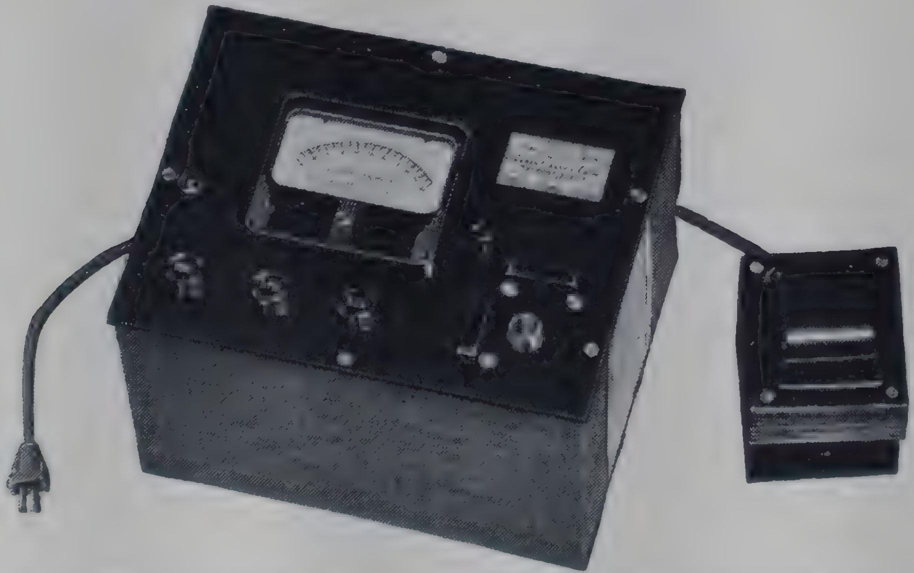


FIG. 11.13. Electronic photofluorometer (Colman Instrument Company).

effect upon ability to fluoresce. Some dyes in powdered form do no fluoresce but when dissolved in solvents show brilliant fluorescence Others show fluorescence on the dyed fabric but neither in solution no in powdered form, and frequently the nature of the fabric as well a percentage in dyeing will markedly influence the brilliance of fluorescence.

Among the organic compounds and dyes which have excellent fluorescent effects are anthracene, β-naphthol, phthalimide, quinine, eosin rhodamine, and fluorescein (*B58*).

There are available on the market a number of instruments which have been designed as fluorimeters, and most of them are designed also as photofluorimeters so as to measure the fluorescent effects with a photronic or photoelectric cell. Among these instruments are the Coleman, Klett, Pfalz and Bauer, Hilger, and Photovolt (see Fig. 11.13). In most of these instruments a powerful ultraviolet source such as that produced from a mercury H-4 lamp illuminates the sample. After invisible light has been removed by means of an ultraviolet filter, the emitted fluorescent light is measured by the current effects produced in a photocell with a sensitive galvanometer. The determination of thiamin provides an interesting example of fluorimetry as a means of chemical analysis.

Fluorometric methods of analysis have been devised for vitamins B_1, B_2, B_6, A, C, E, nicotinic acid, cholesterol, and many other biological and chemical products. As a specific example, the determination of riboflavin may be cited in which a solution of 0.1 gamma per ml is taken as the control standard and the intensity of fluorescent light from the unknown compared with the standard.

The change in the hydrogen-ion concentration of solutions has a marked effect upon the fluorescent color, and indicator effects are obtained with fluorescent colors just as with visible colors. The following examples may be cited to show this effect.

Indicator	Color Change	*p*H Range
Acridine	Green to violet	4.9–5.1
Eosin	Colorless to green	2.5–4.5
Fluorescein	Colorless to green	4.0–4.5
β-Naphthol	Colorless to blue	6–8
α-Naphthylamine	Colorless to blue	3.4–4.8
β-Naphthylamine	Colorless to violet	2.8–4.4
Salicylic acid	Colorless to dark blue	2.5–3.5

The effects referred to with respect to dyeing of fabrics, in which the dye adsorbed on certain fabrics would fluoresce whereas the same dye on other fabrics would not, are in line with the effects shown by a change in pH upon fluorescence. It has also been shown that the fluorescent effects in solvents vary and that the same compound may show markedly different fluorescent colors in different solvents, there being usually a shift to shorter wavelengths of the fluorescent color as the dielectric constant is increased.

LITERATURE

General

A. C. HARDY, "Handbook of Colorimetry" (*B26*).
W. E. FORSYTHE and others, "Measurement of Radiant Energy" (*A23*).
W. S. HOFFMAN, "Photelometric Clinical Chemistry" (*B34a*).
H. E. MILLSON, "The Phenomenon of Fluorescence" (*B58*).
J. A. RADLEY and J. GRANT, "Fluorescence Analysis in Ultraviolet Light" (*B66*).
P. W. DANCKWORTT, "Lumineszenz-Analyse" (*B12*).
H. HIRSCHLAFF, "Fluorescence and Phosphorescence" (*B38*).

See also *Reports* of the Intersociety Color Council and committees of the Optical Society of America.

CHAPTER XII

LABORATORY EXPERIMENTS

EXERCISE 1

CALIBRATION OF MEDIUM-SIZE SPECTROGRAPH (WITH CORNU PRISM)

Optical Principle—Light Path. This experiment illustrates the use of the spectrograph in conjunction with a light source (an arc or spark) and condensing lens, L_3 (Fig. 12.1*a*). It is desirable, but not essential, that this light source and lens be on an optical bench so that adjustments may be made without changing alignment of the optical path. This requires that the optical bench be parallel to the optical path of the spectrograph. A rapid method of determining the optical path is to place a strong single-filament light at K (Fig. 12.1*a*). (Note that K is the extreme right-hand end of the plate opening as one looks into the spectrograph through this opening.) This light path is the reverse of the normal path and makes possible a rapid adjustment of the apparatus. While this adjustment is being made, the slit of the spectrograph should be opened to about 0.1 to 0.2 mm.

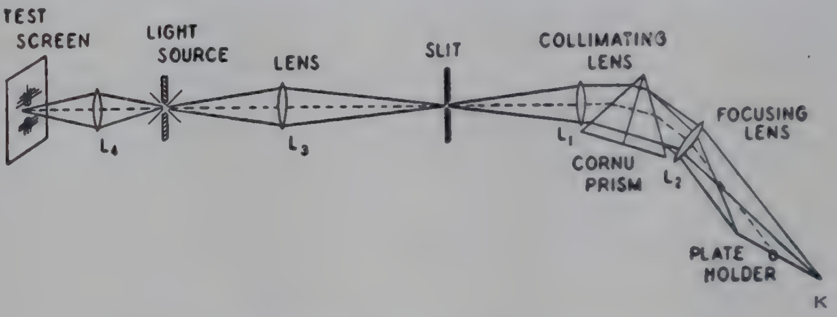


FIG. 12.1*a*. Spectrograph with Cornu prism.

Position of Source-Focusing Lens. The distance between the arc or spark and the spectrograph should be at least four times the focal length of the lens, and it is preferable to use a greater distance and to place the lens at the focal position which produces the larger image, i.e., so that the lens is nearer to the light source than to the spectrograph slit (see p. 50). The choice of lens will depend to some extent on the size of the image to be projected. It is essential to have an image large enough to prevent the appearance of the electrode ends on the transmitting portion of the slit.

Position of Light Source. Once the optical path and focus have been established, it should not be necessary to alter the position of the lens, and any adjustment due to the failure of the image to center on the slit properly should be corrected by vertical or lateral movements of the arc or spark holder. If the light source wanders over the electrodes, it may be necessary to adjust the electrode positions continuously while the photograph is being made. Alignment may also be checked through the auxiliary image on the test screen. If the electrodes are of materials which produce nonconducting oxide layers, it will be necessary to start the arc by touching the electrodes with a carbon rod.

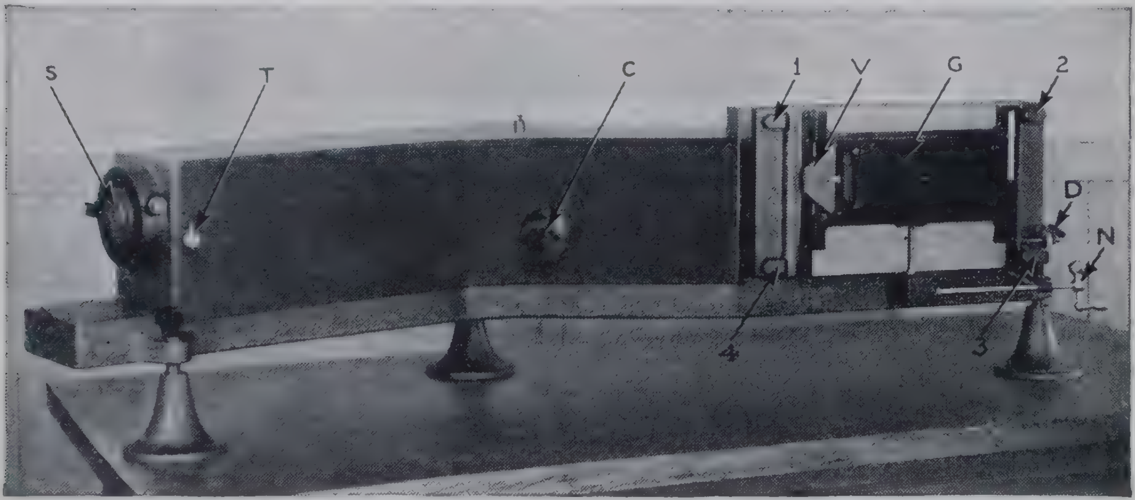


FIG. 12.1*b*. Medium spectrograph (Bausch and Lomb). Focusing adjustment (*C*), slit (*S*), shutter (*T*), plate holder (*G*), dark slide (*V*), plate-holder screw-motion lever (*N*), scale lever (*D*), screw adjustment of plate-holder tilt (1, 2, 3, 4).

Focus of Spectrograph Lens System. The spectrograph itself has many fine adjustments, but most of them are properly made and locked in position so that further adjustment should not be necessary. Such adjustments include the setting of the slit jaws to be parallel with each other, setting the slit so as to be parallel with the refracting edge of the prism, setting the prism at the angle of minimum deviation, and focusing the collimating lens. These pieces should be adjusted or altered with the greatest of care and only when absolutely necessary. For the most part any corrections which seem necessary may be made in the focusing of the lens system (the focusing lens L_2) and the tilt of the plate holder. A focusing screw is usually attached to the lens, L_2 or L_1, by means of which the focal plane of the lens may be shifted.

In the absence of any known focus settings for the instrument, an approximate setting can be obtained by placing a sheet of ground glass in the plate holder at the right-hand end (longer-wavelength end), and removing the back of the plate holder so as to observe the spectrum.

Slit. The width of the slit should be set at 0.02 to 0.03 mm (slit screws are usually graduated in 0.01 mm) and the height of the slit at about 4 mm by means of the wedge or Hartmann diaphragm.

Photographic Plate. Load the plate holder with a photographic plate (Eastman 33 or Spectrum Analysis No. 1 are recommended since development can be easily observed with a No. 1 Wratten safelight). The plate should be numbered before leaving the dark room by writing with a pencil on the emulsion side at one end or a corner of the negative. This number should appear on the notebook or plate record sheet.

The observer should be careful in putting the negative into the plate holder so as to avoid fingerprints or abrasion marks on the emulsion side of the negative and should be certain that the emulsion side of the negative faces the safety dark slide of the plate holder. Putting the negative into the holder with the glass side facing the dark slide will result in a change of the focal plane by a distance equivalent to the thickness of the glass negative, thus throwing the spectrum out of focus, and, since glass is opaque in the ultraviolet beyond a wavelength of about 300 mμ, wavelengths shorter than this will not be transmitted to affect the photographic emulsion.

Experimental Procedure. A series of photographs are taken by moving the plate holder a definite distance at right angles to the spectrum, and at each setting a different focus value is used. The plate holder is usually moved by a gear or screw motion along a track with a graduated millimeter scale. The motion for each successive photograph should be about the same as the height of the slit (4 mm). The plate motion, like all other adjustments on the spectrograph (*except slit closing*), should be in a positive direction, i.e., from lower to higher positive values. If for any reason the motion exceeds the desired setting it is advisable to return to a position considerably behind the position desired and proceed in a positive direction to the point so as to avoid any instrumental back lash in the screw or rack motion. The series of photographs, as indicated in the accompanying sample data sheet, should start at a focus setting considerably below the approximate focus and should be increased in a positive direction until one has gone considerably beyond this approximate focus setting. For example, if the approximate focus is observed at a setting of +0.2 on the focus screw and it is apparent that settings of +1.0 and −1.0 are decidedly out of focus a series of photographs might be taken as indicated in the sample record sheet (Table 12.1).

Among the points to be observed are such routine procedures as:

1. Properly "facing" the photographic negative in the holder.

2. Opening of the dark slide of the plate holder *after* racking or sliding into position on the spectrograph.

TABLE 12.1

Spectrographic Analysis

Plate No.[1]................ Observer.................
Instrument................ Date.....................
Emulsion................ Developer................

No.	Check[2]	Plate Motion[3]	Sample	Time	Source	Slit	Focus
1	✓	0 mm	Scale				
2	✓	4	Brass B-2	4 sec	Arc	0.02	−1.0
3	✓	8	Brass B-2	4 sec	Arc	0.02	−0.5
4	✓	12	Brass B-2	4 sec	Arc	0.02	−0.2
5	✓	16	Brass B-2	4 sec	Arc	0.02	0.0
6	✓	20	Brass B-2	4 sec	Arc	0.02	+0.1
7	✓	24	Brass B-2	4 sec	Arc	0.02	+0.2
8	✓	28	Brass B-2	4 sec	Arc	0.02	+0.3
9	✓	32	Brass B-2	4 sec	Arc	0.02	+0.4
10	✓	36	Brass B-2	4 sec	Arc	0.02	+0.6
11	✓	40	Brass B-2	4 sec	Arc	0.02	+1.0
12	✓	44	Scale				
13[4]	✓	50	Brass	6 sec	Arc	0.01	+0.2
14	✓	54	Brass	4 sec	Arc	0.02	+0.2
15	✓	58	Brass	2 sec	Arc	0.05	+0.2
16	✓	62	Brass	1 sec	Arc	0.10	+0.2
17	✓	66	Scale				

[1] The plate number should always be recorded on the data sheet or in the record notebook as well as on the negative.

[2] Check each exposure when completed.

[3] All adjustments and settings involving a screw or rack motion and measured by a graduated scale should be made in a positive direction only. If the screw is graduated in both directions from a zero indication, one direction, preferably right, must be marked as positive, and settings made in a direction towards greater positive values.

[4] Since the usual plate motion is about 80 mm (for a 4 by 10 inch plate) it would be of interest to test the effect of width of slit on the appearance of spectral lines. To do this the instrument should be set on its approximate focus and the indicated photographs taken on the bottom of this plate.

3. Swinging the scale into position before turning on the scale lamp.

4. Turning off the scale lamp after the scale exposure is made.

5. Swinging the scale out of position after the scale exposure is made.

6. Screwing or racking the plate holder to higher settings after each exposure and properly checking the observation record on the sheet.

7. Opening the shutter before making exposures if the spectrograph is equipped with a shutter.

8. Checking the slit and focus settings.

9. Making the proper record on a data sheet or notebook of the nature of each sample observed.

10. Observing the same precautions for the scale at the end of the plate as at the beginning.

11. Completely closing the dark slide before removing the plate holder from the spectrograph.

12. Being sure that the negative number agrees with the number on the data sheet.

Development of Plate. In a laboratory in which regular spectrographic analyses are made, standard developer solutions and a time-temperature control on the developing process will usually be provided. For instructional purposes and to avoid contamination from developers used by different workers where a large number of people must work with the equipment, it is suggested that each group or section of workers should prepare its own developer solutions. For this purpose the standard M-Q (elon-quinol) developing powder tubes are quite satisfactory. The solution is prepared by dissolving first the A powder and then the B powder in 250 ml of water at 70° F. A 250-ml graduated cylinder is convenient for the solution preparation, and if the carbonate powder (B) is added rapidly and shaken quickly and thoroughly it will not tend to form the less-soluble hydrated form but will go directly into solution.

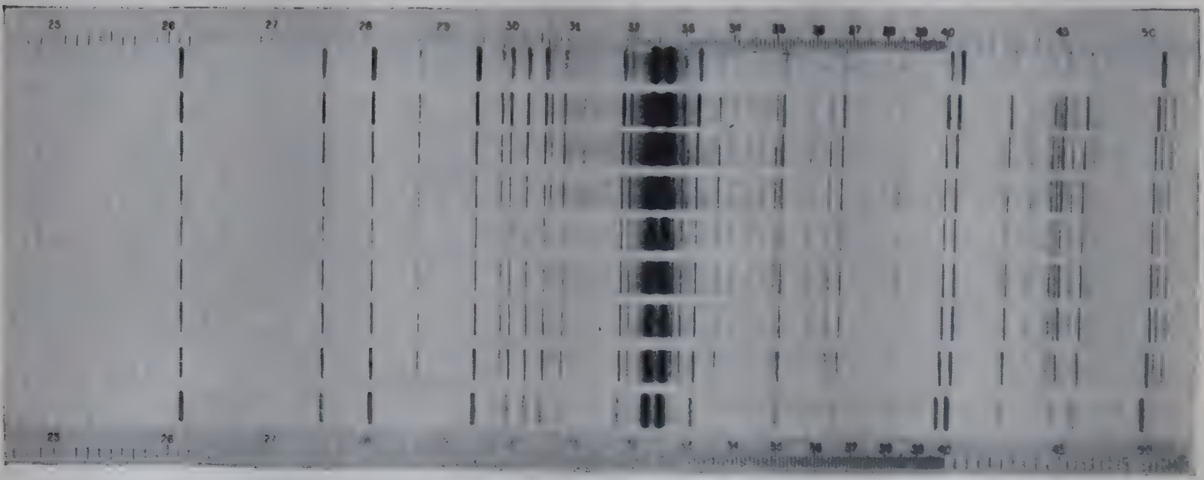


FIG. 12.2. Focus negative (Exercise 1).

The plate should be developed about 1.5 to 2 minutes or until inspection from the back (glass) side with a No. 1 Wratten safelight shows the spectral image as having distinctly penetrated the emulsion. For more accurate work a time-temperature-developer control is essential to produce the desired gamma (see section on photography), but for focus calibration and qualitative analysis the above technique is quite satisfactory.

After development the plate is washed for about half a minute with water containing a small amount of acetic acid and then placed in the hypo (sodium thiosulfate) solution to clear. After the plate has been in the hypo for half a minute the white lights in the dark room may be turned on and the remainder of the procedure conducted in normal room lighting. The negative should stay in the hypo for about 10 minutes after the last visual trace of silver halide (opaque light yellow color) has disappeared. It should then be washed for 15 to 30 minutes in running water at about 65 to 70° F. Before being placed in the drying rack the negative should be carefully washed with a wet hand, cotton swab, or viscose sponge to remove any scum or deposit which may form as a result of hard water or other adhering materials.

Examination of Negative—Report of Results. The dry negative should be carefully examined with either a projection apparatus or a reading magnifier (such as the Bausch and Lomb magnifier with a built-in scale). The report on the experiment should indicate the setting which produces the best focus in the middle of the spectrum or plate. In addition, the observer should examine the two ends of each spectrogram, and from the focus of the lines at the ends of the spectrograms he should indicate the most satisfactory focus settings for the long- and short-wavelength ends of his negative. If these latter values are not found in the same spectrogram or the same setting as the satisfactory center focus the observer should indicate the direction and amount of rotation that should be given to the plate to produce a more satisfactory focus adjustment.

Problems. 1. The higher positive values of the focusing screw move the focusing lens nearer to the plate,[1] thus moving the focal plane away from the prism. If the spectrum is in focus at the low-wavelength (left) end at a setting of -1, in focus at the center at $+1$, and in focus at the long-wavelength (right) end at $+3$, indicate the correct setting and the direction of rotation of the plate holder which should be made about its center (0 in Fig. 12.1*a*).

2. Indicate the cause of each of the following observed effects.

(*a*) A negative taken on a medium-type spectrograph appears to be slightly out of focus from 6000 A to 3600 A. The rest of the spectrum below 3600 A does not appear, although the cut-off is not sharp.

(*b*) The spectrogram has a fine white streak or line perpendicular to the spectrum lines.

(*c*) The spectrogram has a fine black streak or line perpendicular to the spectrum lines.

(*d*) A black streak about 1 inch wide appears on the negative

(*e*) Different element lines appear in the top and bottom regions of the spectrogram.

(*f*) The negative is a clear blank with no spectrum lines although the scale appears. (Give three explanations.)

---

[1] Bausch and Lomb instrument.

EXERCISE 2

QUALITATIVE IDENTIFICATION OF ELEMENTS

This exercise is divided into two parts: (*a*) the identification of the lines of a known element, and (*b*) the determination of the wavelength values of the lines of certain unknown elements and the identification of elements which produce them.

Samples. It is suggested that a pure sample of copper be used for the first part, and a brass, aluminum alloy, or die-cast alloy for the unknown. One should avoid an unknown alloy containing iron or other elements which produce a large number of lines.

Another type of sample which may prove very satisfactory for the known and unknown in this experiment would involve the use of carbon electrodes (National Carbon spectroscopic grade are sufficiently pure) and salt mixtures. It is suggested that the known material be a salt (preferably a carbonate) of lead, zinc, tin, magnesium, antimony, or copper, and that the unknown be a prepared mixture of three or more of the above salts including the one which has been chosen for the known.

TABLE 12.2

SPECTROGRAPHIC ANALYSIS

Plate No. . . . . Analysis for . . . . Observer . . . .

Instrument . . . . *Copper—Brass* . . . . Date . . . .

Emulsion . . . . Developer . . . .

No.	Check	Plate Motion	Sample	Time	Source	Slit	Focus
1		10 mm	Scale				
2		14	Copper (std)	5 sec	arc[1]	0.02[1]	+0.2
3		18	Brass C-3	5 sec.			
4		22	Scale				
5 . . . 15[2]							

[1] On spectographic data sheets it should be understood that, where there is no change in the method slit width, focus, etc., on a plate, an entry at the top of the column is sufficient.

[2] The observer should either repeat these photographs on the remaining part of the negative or run another unknown in this space.

Experimental Procedure. If the instrument does not have a Hartmann diaphragm, the V-wedge in front of the slit should be set so as to give a spectrum about 4 or 5 mm wide, and the plate motion should be moved by this amount so as to keep the scale and spectra in contact. If the instrument is equipped with a Hartmann diaphragm, the known and sample photographs should be taken by leaving the plate holder in a set position and moving the diaphragm so as to illuminate adjacent portions of the slit. Care should be exercised that sufficient plate movement is made so that the scales will not be superimposed on the spectrum photographs. Arc exposures should be made of the samples, using a current of about 4 amperes and a voltage drop across the electrodes of about 50 volts. (Table 12.2.)

Development of Negative—Preparation of Chart. Develop the negative in the usual manner (see Exercise I and section on photography), being careful to wash the plate thoroughly after removing it from the fixing bath, and also to wash off with moistened cotton, viscose sponge, or with the hand any surface dirt or deposit prior to putting it into the drying rack. When the negative is dry put it into the enlarging machine (emulsion side down), and project the image so as to give a spectrum between 2400 and 5300 A of about 28 to 30 inches. Such an enlargement will be about 3 to 3½ inches wide and can be made on three strips of 4 by 10

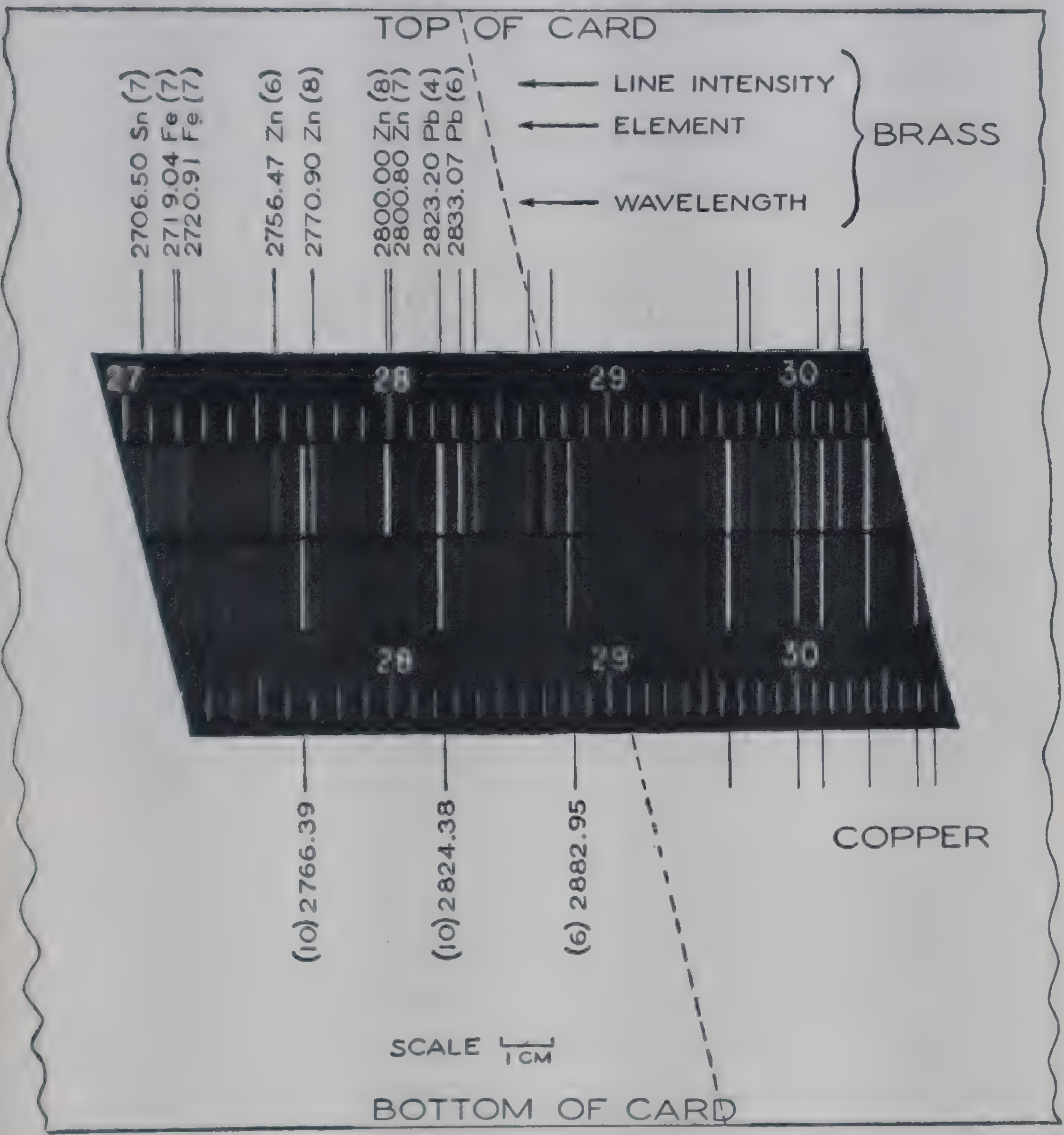


Fig. 12.3. Enlarged section of mounted and partially identified spectra. **P.**

inch Eastman News Bromide or Agfa Brovira (contrast) paper. Most enlarging machines will not project the entire 8- or 10-inch negative at one time but will require moving a negative of this size in the holder so as to produce three separate sections which may be combined to produce

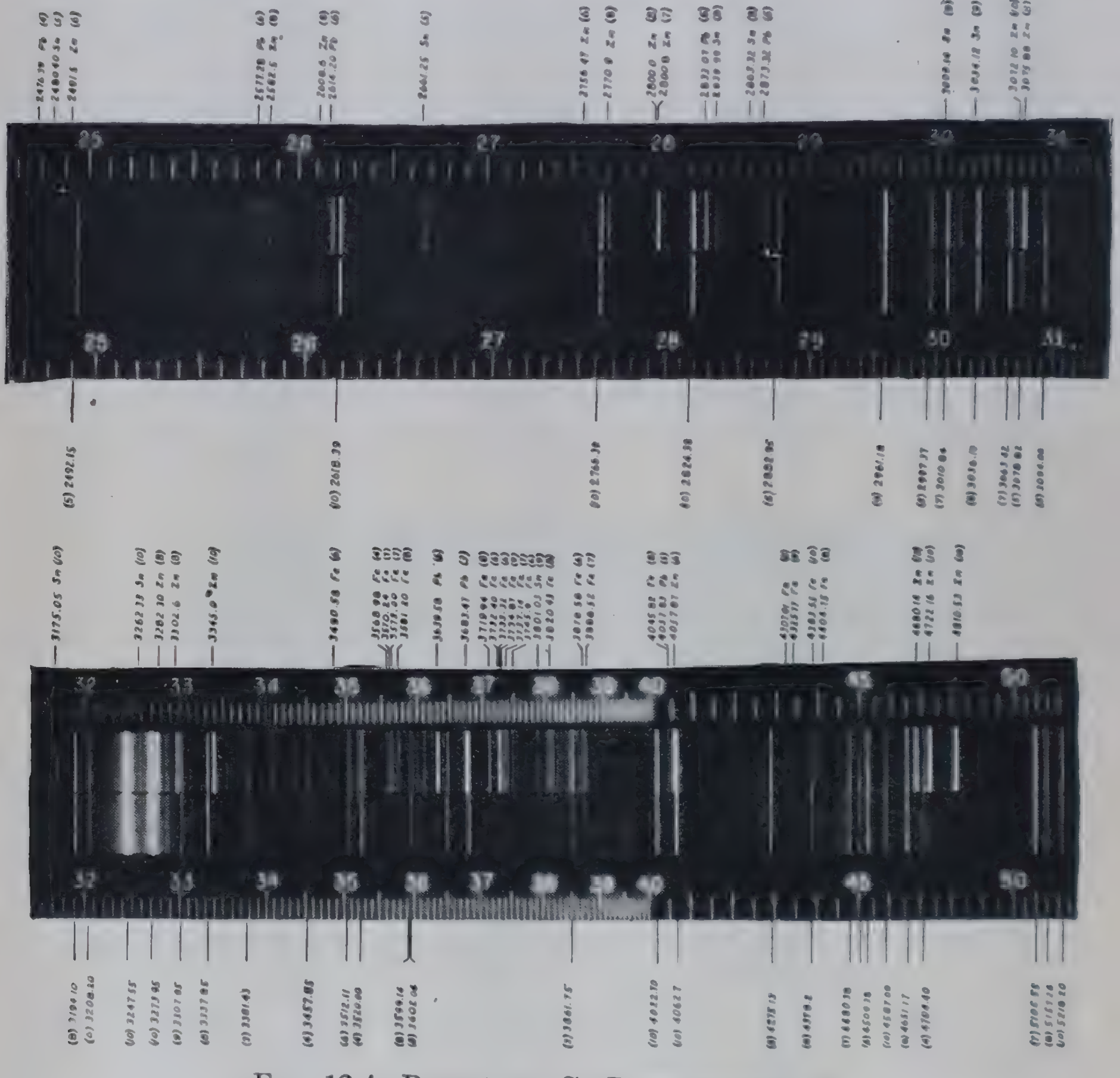


FIG. 12.4. Report on Cu-Brass analysis. P.

a complete enlargement of the negative (Fig. 12.4). The prints should be exposed to give a maximum gamma, and developed in M-Q or Agfa 125 developer. When dry the prints are to be trimmed and mounted on an 11 by 28 inch card with dry mounting tissue or rubber cement.

Identification of Standard Lines. Lines should be drawn on the card adjacent to each spectrum line, and the standard lines identified by reference to tables and by the photographed scale. For the identification of the standard lines it is suggested that one use the spectrum tables in the "International Critical Tables," in the "Handbook of Chemistry and Physics," or in this book (page 445).

Starting with the strongest lines as indicated in the Table (in the case of Cu, the pair of 3247 and 3272A) the remaining medium and then the weaker lines can easily be identified, especially with the aid of the approximate wavelength values as given by the printed scale.

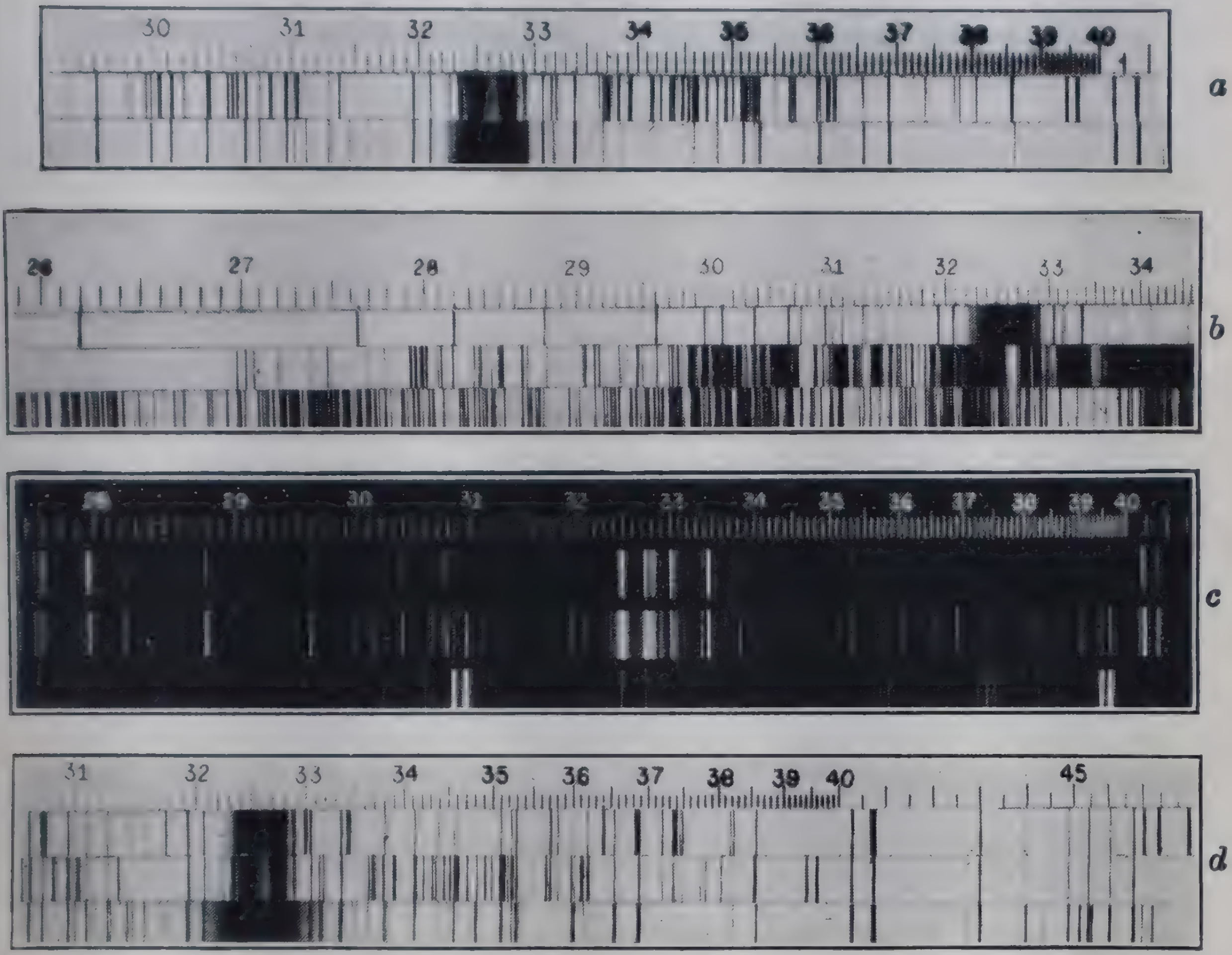


Fig. 12.5. Examples of spectrogram for quantitative elemental identification (*a*, *b*, and *d*; **N** - *c*; **P**).

Identification of Unknown Lines. For the identification of lines other than the standard element in the unknown sample, one should use the table of persistent lines of the elements arranged by wavelengths, which is to be found in the same collection of spectrum tables (page 410) in this book, starting first with the strongest lines. For example, if an unknown line of 2850 A is present, it may be recorded as 2839 (Sn), 2843 (Cr), 2848 (Mo), 2849 (Cr), 2852 (Mg), 2854 (Pd), etc., depending on the accuracy of the photographed scale. In addition, the line may be a weaker line of some other element which is not given in these very abbreviated tables. For the preliminary survey it is best not to consult the very extensive tables such as Kayser's "Hauptlinien" or Harrison's 100,000-line table. In the above example, the persistent lines as arranged by elements should be consulted first; then the position of other persistent lines of the possible elements should be noted and looked for in the photograph. If three or more lines agree, the presence of the element is practically certain. After identification of the element the wavelength tables for that particular element should be consulted, and the other strong lines of the element in the photograph identified.

An example of the method in which the data should be recorded is given in Fig. 12.4. The three strips should be mounted on the 11 by 28 inch card with dry mounting tissue or rubber cement, overlapping spectral regions being cut off so as to make a continuous strip, and, if the strip is longer than 28 inches, some of the short-wavelength end should be cut off to fit the card.

Reference Tables. For the solution of this exercise use the following tables (in this book) in the order indicated:

(*a*) Copper spectrum. Table VI, p. 475.
(*b*) Persistent lines by wavelength. Table II, p. 402.
(*c*) Persistent lines by elements. Table III, p. 405.
(*d*) Analysis lines. Table IV, p. 408.
(*e*) Principal lines by elements. Table VI, p. 445.
(*f*) Principal lines by wavelength. Table V, p. 410.

Problems. 1. Indicate the wavelength of the unknown lines in an assigned portion of Fig. 12.5*a*, *b*, and *c*, and identify the elements producing these lines.

2. Indicate the wavelength of the unknown lines and the elements producing these lines in the upper spectrogram in Fig. 4.8.

EXERCISE 3

CALIBRATION AND ADJUSTMENT OF A LITTROW SPECTROGRAPH

Optical Principle. The Littrow spectrograph (Fig. 12.6) embodies the same general optical principles as the Cornu prism type of spectrograph described in Exercise 1. The essential difference is that a single 30° prism is used rather than the two 30° prisms which make up the Cornu prism. The back or altitude face of the prism is coated with an aluminum or tin amalgam so as to reflect the light back through the prism. The total light path thus is equivalent to a 60° prism, and any double refraction produced by the quartz as the incident beam passes through it is corrected in the reflected beam. The lens (L_1) also serves the double function as the collimating and focusing lens.

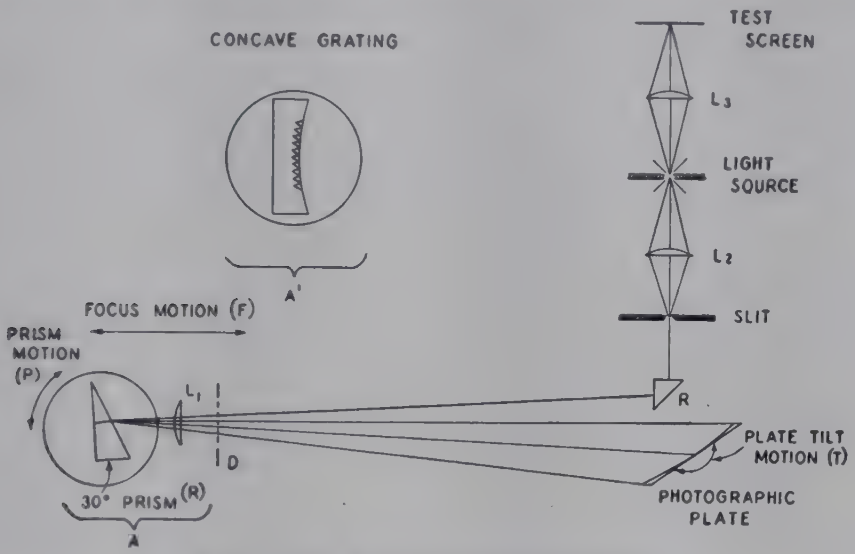


Fig. 12.6. Littrow spectrograph.

Some Littrow instruments are equipped with interchangeable sets of glass and quartz prisms and concave gratings. The most acceptable type of grating instrument for general analytical work is that in which a concave grating (A') takes the place of the lens (L_1) and prism (P) in the Littrow mounting. This concave grating mounting (see Fig. 3.13) is known as an Eagle mounting (A'). The procedures of adjustment and calibration for the grating and prism system are alike. Both types of instruments require the refracting axis, edge of the prism or the lines of the grating, to be parallel to the slit and perpendicular to the optical path of the spectrograph.

From a theoretical point of view the incident and dispersed beam should be centered in the same path; but this would be possible for one wavelength only, hence there is no serious objection to the spreading of the two beams so that the reflecting prism (R) of the incident beam lies just on the edge of the plate field. Placing this to one side avoids the obstruction of a portion of the photographed spectrum.

Slit Illumination. For purposes of obtaining uniform slit illumination (see section on quantitative spectrographic analysis) it is sometimes advisable to place the condensing lens of the slit illumination system as close to the slit as possible and to place the light source so as to focus on the lens of the spectrograph. Such a modification of the conventional system of illumination is rather inefficient with regard to the dispersing system but permits the masking of the electrode ends of the light source (diaphragm [*D*], Fig. 12.6) and at the same time provides uniform illumination of the slit.

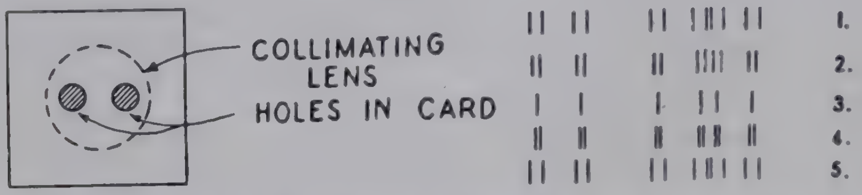


FIG. 12.7. Effect of a two-hole diaphragm in focus adjustment.

The rather long path between the condensing lens and the spectrograph lens, as compared with the distance between the light source and the condensing lens, requires that the position of the light source be accurately determined and maintained in order that the image of the electrode ends may be properly masked (D) at the spectrograph lens (L_1), and the remainder of the arc fill as much of the spectrograph lens as is possible. To provide an accurate control of the position of the light source it is suggested that a supplementary lens (L_3) and a screen (S) be provided in the optical path. The optical path of the spectrograph can easily be established by setting the prism to a visual spectrum setting and placing a light at the position of the plate holder. The slit should be opened to about 1 mm and the location of the lens (L_2), light source (LS), auxiliary lens (L_3), and test screen (S) established.

Focusing. The focusing of a Littrow spectrograph involves three separate adjustments: (*a*) the focus setting of the lens, (*b*) the tilt of the prism, and (*c*) the tilt of the plate holder. The most sensitive of these adjustments is the tilt of the prism, so that for most adjustments this is set at approximately the correct setting as determined from known settings, or by observation with a ground glass in the visible portion of the spectrum, and the other two settings changed until adjustment is reached. By illumination of separate areas of the lens (L_1) with a two-hole diaphragm one can easily see a doubling effect when the instrument is out of focus (Fig. 12.7).

Usually each instrument of this Littrow type has a special table of settings calibrated for that instrument so that it will not be necessary as a rule to make the rough approximations as described above. The laboratory experiment involves the checking of one of the settings from an accepted list for the instrument used. In this experiment a series of 10 photographs is to be made at varying focus settings, starting 4 units below the accepted value and changing the focus in unit increments for each photograph until a focus setting of 5 units above the indicated setting is reached.

Table of Settings. The following settings are given as an example of adjustments. These have been tested and found satisfactory for a Hilger Littrow Spectrograph (E 185):

TABLE 12.3

Focus Settings for Hilger Littrow Spectrograph (E 185)

Setting No.	Range Covered	Prism[1]	Focus[1]	Plate Tilt
1	2180–2455 A	64–18	126–10	64.2
2	2404–2794	65–15	141–04	64.9
3	2706–3286	66–12	157–00	65.9
4	3258–4448	67–09	174–00	67.2
5	3669–5324	67–17	182–18	67.6
6	4200–8000	68–02	189–04	68.5
7	2894–3690	67–00	164–10	66.3

[1] It should be noted that focus and prism values on this instrument are operated by screw motions with graduated scales which are divided into *20 parts per large scale division* and not in the usual decimal or 10 parts.

This is an unusually large instrument having a focus of 3 meters as compared with a focus of approximately 1.75 meters for other large Littrows.

Automatic Instruments. Adam Hilger, Ltd., also manufactures an instrument (E 492) which is fully automatic, i.e., the three adjustments (prism, focus, and plate tilt settings) are made simultaneously by one control. This instrument has a focus of 1.7 meters.

The Bausch and Lomb Optical Company's large Littrow spectrograph is semiautomatic, in that coordination between focus and prism rotation is secured by means of a cam, which causes the prism to rotate as it is moved forward or backward in focusing. Eleven fine-pitch micrometer screws are inserted in this cam at suitable intervals, and each of these is accurately adjusted so that, when the screw carried on the arm which rotates the prism table bears on the end of a given screw, the portion of the spectrum is brought on the plate which is in focus with that position of the focusing carriage. The plate tilt is adjusted by a separate control. The focus of this instrument is approximately 1.8 meters.

The Hilger E 492, the Bausch and Lomb, and the Gaertner Littrow instruments have approximately the same focus, dispersion, and resolving power.

Although these instruments are fully or partly automatic the directions given above for making adjustments apply to them if any one of the three settings becomes thrown out of adjustment and thus all three must be readjusted.

Experimental Procedure. Exposure should be made with a slit width of 0.02 to 0.03 mm, with an iron arc (4-ampere 50-volt drop) as a light source and exposing for 10 to 15 seconds. The same precautions and technique are required as in the exposures described in Exercise 1. The negative should be developed as indicated in Exercise 1 and the section on photography (page 363).

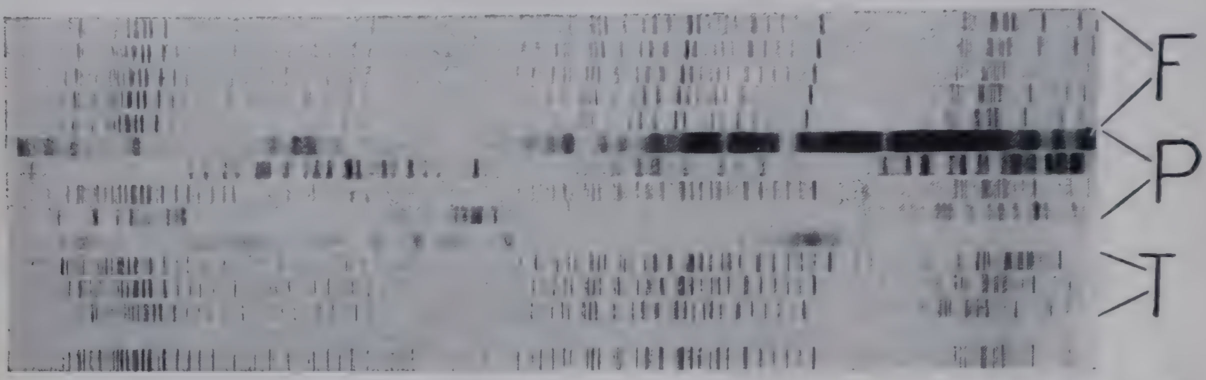


FIG. 12.8. Focus negative (Exercise 3). F = focus adjustment, P = prism tilt, T = plate tilt. N.

Report. The negatives obtained should be examined as in Exercise 1. The report should confirm the setting or a suggestion made for its correction if the setting appears to be in error.

Problem. Plot the above Table 12.3 prism, focus, and tilt values (or data supplied with the laboratory instrument if such are available) against the range limitations. From these data determine approximate settings and upper range for a setting which yields a spectrum with its lower wavelength edge at 2600 A.

EXERCISE 4

IDENTIFICATION OF A PORTION OF THE IRON SPECTRUM; PREPARATION OF A CHART FOR THE QUALITATIVE IDENTIFICATION OF AN UNKNOWN

Preparation of Spectrum Enlargement. A negative (Fig. 12.9) with a satisfactory iron spectrum, such as obtained in the final test run in Exercise 3, should be marked off into 10 numbered spaces of 25 mm (1 inch) of the spectrum. Prepare enlargements of each section 10 times the original size. One section is to be assigned to each student, who will mount the photograph as indicated below and identify the iron lines in the 10-inch photographic strip. It is suggested, for the enlargement of the small portion of this negative to 10 times its size, that a miniature film enlarger be used. These enlargers are designed to cover a field of about 1 inch and give better definition in the final print.

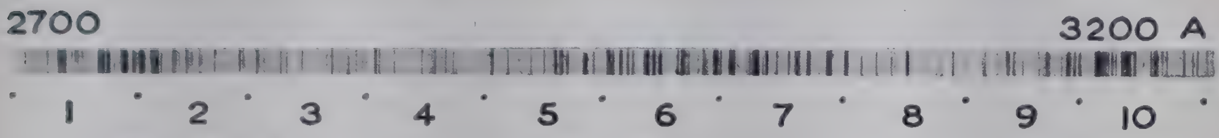


Fig. 12.9. Iron spectrogram with indicated division assignments. **N.**

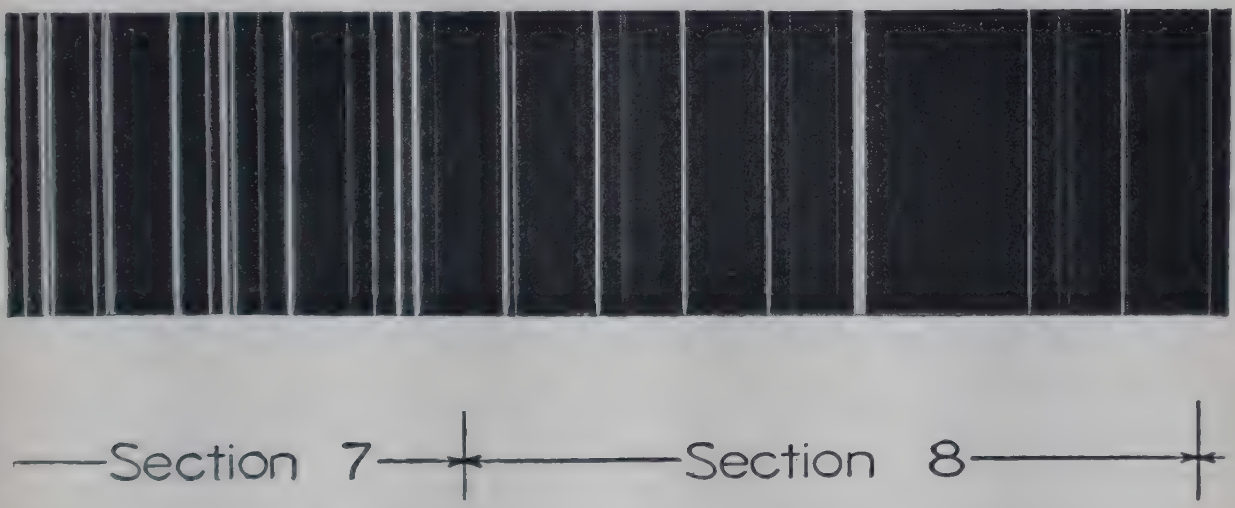


Fig. 12.10. Enlarged section of Fig. 12.8. **P.**

Mounting of Enlargement. The final print should be at least 1 inch wide and is to be mounted in accordance with the arrangement shown in Fig. 12.11. The strip should be set so that its bottom edge is 1½ inches from the bottom of the card. Above the strip and scale there should be a blank space upon which the spectra of unknowns may be projected. Above this space are to be indicated the principal lines of other elements which would appear in this region if the elements were present in the unknown. The number of lines indicated in this section will depend on the spectral region.

Identification of Iron Lines. In order to start in the identification of the spectrum, two iron lines should be identified by the instructor or from standard iron charts after the photographs have been mounted. The remaining iron lines should be identified from iron tables (page 489) as far as possible without reference to the available iron charts such as Hilger, Bardet, Crook, or the charts in this book (Plates II to XXXVI).

Wavelength Scale. The wavelength scale between the two spectra should be composed of unit lines not over ⅛ inch high and numbers about ⅛ inch high. The scale should be printed on the card after the iron lines have been identified, and if an instrument of high dispersion is used it will be satisfactory to divide units of 10 angstroms into 10 equal divisions, even though there is a slight convergence of the scale toward the long-wavelength end. If the instrument used does not have a high dispersion it will be necessary to make such divisions only into units of 5 angstroms.

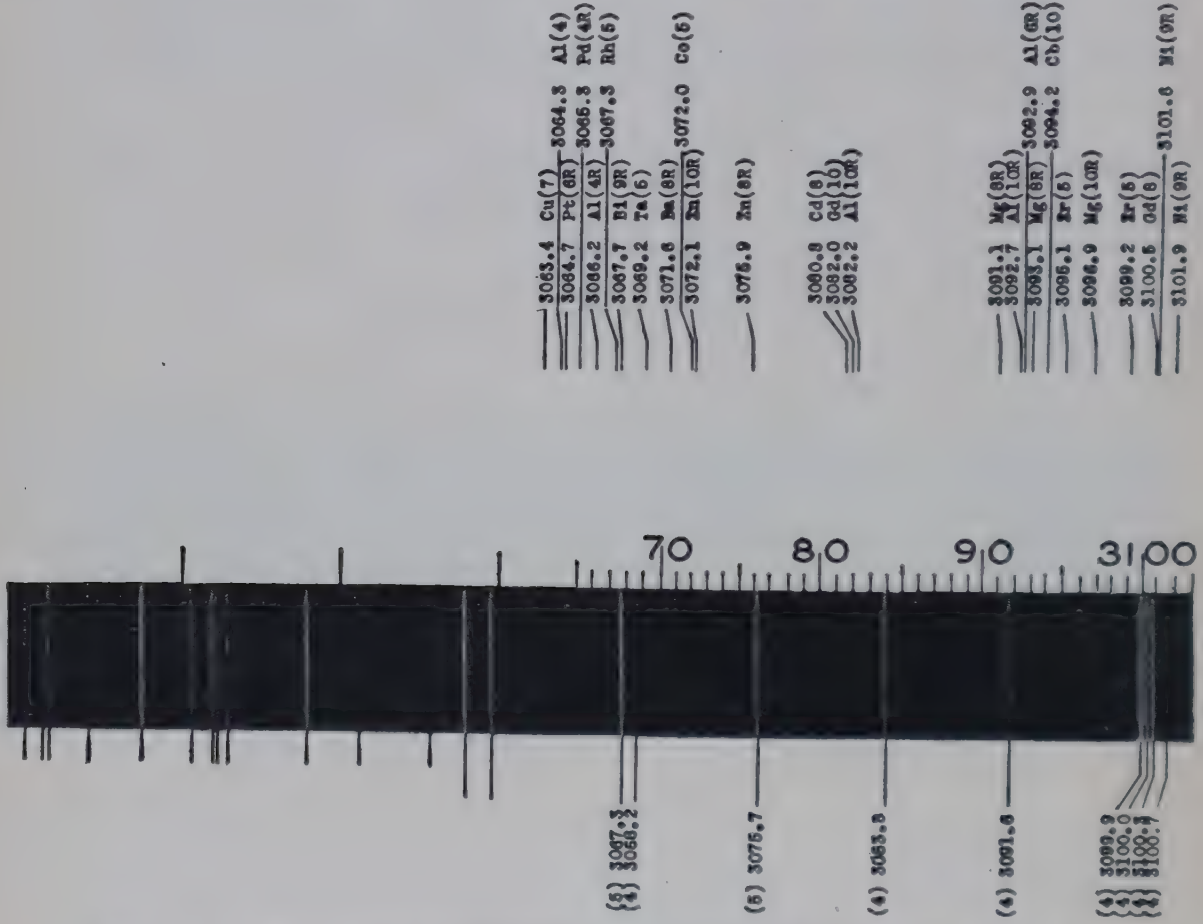


FIG. 12.11. Mounting arrangement and partially completed card. P.

Comparison Lines. The lines to be included in the group of unknown-element lines at the top of the card should be taken from the table of lines arranged according to wavelength (page 410). The number of these lines to be included should not be over 50 on any card. In recording these identification lines, include the wavelength in angstroms to one decimal place, the element symbol, and the indicated intensity on the 10 to 9000 scale, i.e., 2519.2 Si (I 300). So far as possible one should record all these identification lines in a single row on the card, but if there are too many in any particular portion of the card a second or even a third row may be required. The selection can be made by the use of intense lines (boldface and ordinary type in Table V), and omitting the weak lines (italic type). It will be necessary to look up these lines in the tables of lines arranged by elements (Table VI) so as to obtain the intensity and first decimal angstrom value. (See Fig. 4.6 for examples of completed chart.)

If the class is sufficiently large a complete spectrum table may be prepared in addition to the students' obtaining some experience in the identification of spectrum lines. Individual workers or small groups will not find it of advantage to prepare more than one or two of these cards per person, and hence a reduced set has been included in this book to permit rapid identification of qualitative unknowns (Plates II to XXXVI). (See Exercise 5.)

Note: The spectrum charts given in this book (Plates II to XXXVI) as well as the sample charts for this exercise (Figs. 4.5 and 12.11) give wavelength and intensity values based on the Kayser "Hauptlinien (*A55*) Tables." The wavelength and intensity values given in the tables in this book (Tables I to VIII, pages 400 to 610) are based on the "M.I.T.-Harrison 100,000 Line Tables" (*A39*).

Problems. 1. Complete the iron-line identification in Fig. 12.11 by reference to the iron table (pages 489 to 509). From the table of lines by wavelength (Table V) indicate the approximate position of the stronger lines of other elements in the range not completed in this figure.

2. The intensity and wavelength values in Plates II to XXXVI in this text are given on the data obtained from Kayser (*A55*). Covering a similar spectrum range to an assigned plate, indicate the intensity values and wavelength correction as obtained from the "Harrison-M.I.T. Tables" (*A39*). (The Harrison-M.I.T. values are used in Tables V and VI in this book.) From the table of lines by wavelength (Table V) indicate lines that should be added to or omitted from the assigned spectrum chart.

EXERCISE 5

QUALITATIVE IDENTIFICATION OF ELEMENTS PRESENT IN A STEEL SAMPLE

This exercise is designed to illustrate the use of photographic charts for the qualitative identification of elements and the use of the iron spectrum as a reference spectrum in place of a printed numerical scale.

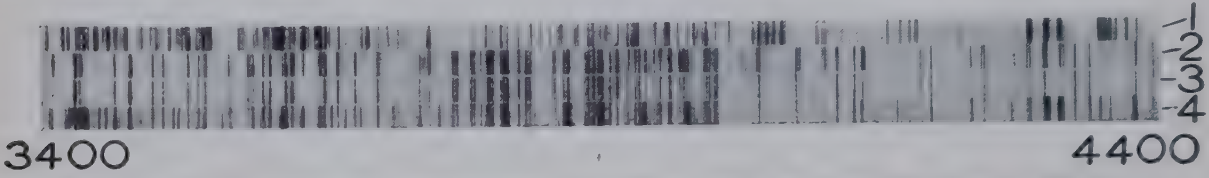


FIG. 12.12. Unknown spectrogram. (1) Nonferrous alloy. (2) Steel. (3) Iron. (4) Steel. N.

Scale and Comparison Spectrum. Because of the variety of positions of adjustment that are possible with a spectrograph of the Littrow type, it is impractical to print a scale graduated in wavelength values on the photographic plate, as is done in the smaller Cornu-type spectrograph. In some of the more recent Littrow instruments, the design has been

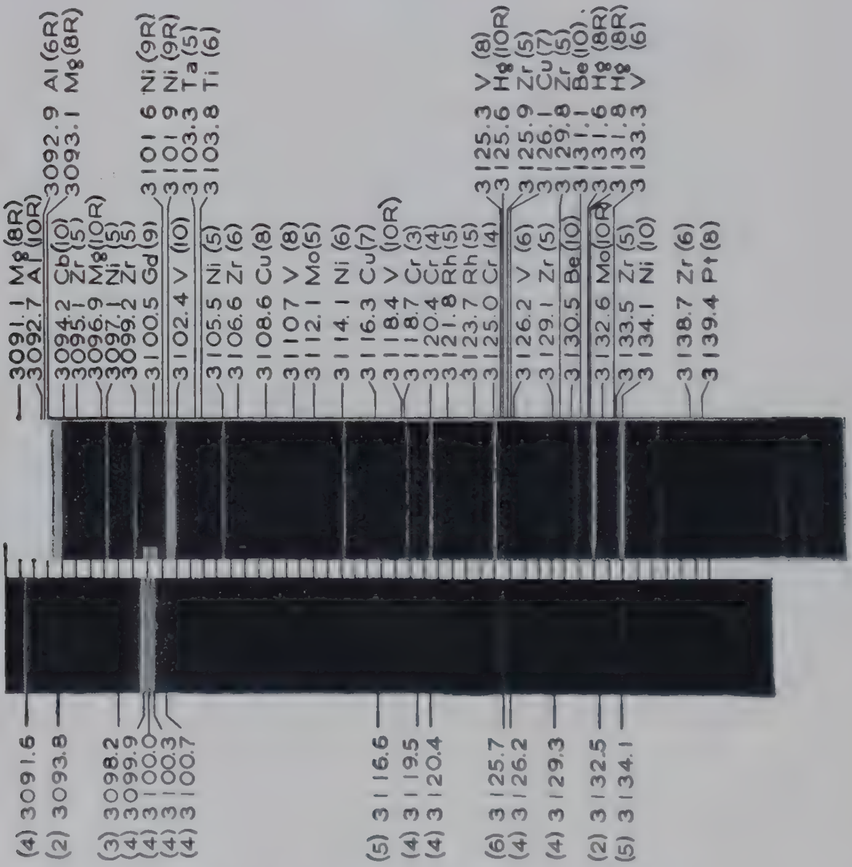


FIG. 12.13. Use of cards for identification of elements (unknown spectrum enlarged to approximately the same scale as the card spectrum and enlargement strip (P) held in correct position). (*Note:* In the examination of nonferrous unknowns it is necessary to record on the original negative an iron spectrum in juxtaposition to the unknown and include this in the enlargement as shown.) This iron spectrum insures correct alignment of the strip on the card.

altered so as to permit rapid adjustment and resetting to previously determined spectral ranges so that the use of a scale either in angstroms or in linear values is not an impossibility.

The iron spectrum has a very large number of lines, many of which have been determined with great accuracy so that some of them form part of our spectrum standards from which the wavelength values of other lines are determined. Because of the large number of iron lines the iron spectrum is essentially a graduated scale which can be printed onto the negative adjacent to the unknown spectrum, and the position or wavelength of the unknown line determined by its relative position between known iron lines. Although the iron spectrum is not so evenly graduated as a regular scale, it is a great deal more accurate than any scale which could be drawn and photographed on the negative.

Experimental Procedure—Preparation of Chart. For this experiment the spectrum of a steel sample is to be photographed and a 10 times enlargement prepared as in Exercise 4. For routine analysis it would not be necessary to enlarge this strip, but merely to project it on an identified iron-unknown card as obtained from Exercise 4, Plates II to XXXVI, or such charts as those given by Bardet, Crook, or Pierce, and to identify the unknown lines from the projection. If there are a large number of students in the group it is more satisfactory to use enlargements, making a strip about 3 inches wide and making 10 strips from a given negative, i.e., one print each from the 1-inch divisions of the negative. Each strip is then cut into three strips 1 inch wide, and each student identifies the elements other than iron present in a set of strips, using the cards prepared in Exercise 4 or Plates II to XXXVI for reference and identification (Fig. 12.13). The number of strips to be identified by each student will depend upon the amount and number of elements other than iron present in the sample. A sufficient number of strips should be assigned to each student so that there will be at least 50 lines (not 50 elements) other than iron to be identified.

Identification of Elements. In identifying the elements three steps are involved:

1. The wavelengths of all the unknown lines should be determined.
2. Tables of persistent lines, arranged according to wavelength, should be consulted in order to identify the elements present. If the persistent lines of a suspected element are not to be found in the spectral section under observation, the high-intensity lines of this element should be sought, as given in the tables of principal lines.
3. Check these possibilities by reference to the tables of persistent and principal lines arranged according to elements.

Report of Experimental Results. At least three lines of an element must be present for positive identification. The report should indicate the elements and wavelength values observed.

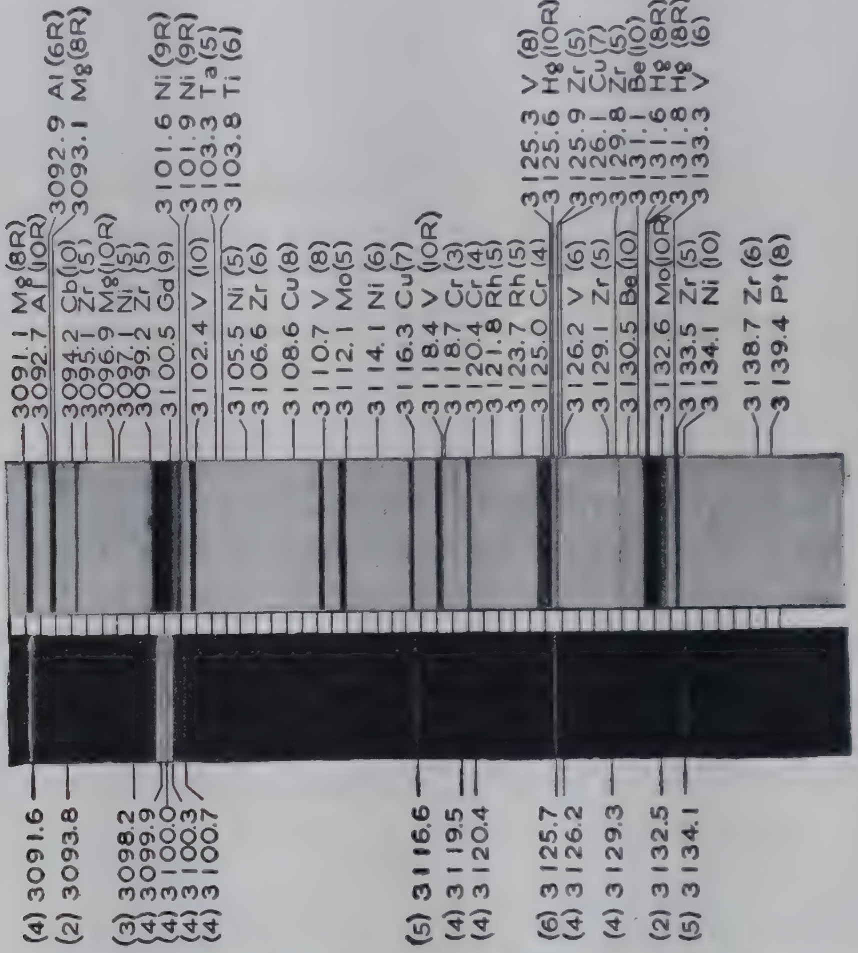


FIG. 12.14. Use of cards for identification of elements. (Projection of unknown spectrogram with enlargement to the same scale as the card spectrum.) (*Note:* In this example the unknown is an iron-containing compound and hence no adjacent iron spectrum is required.)

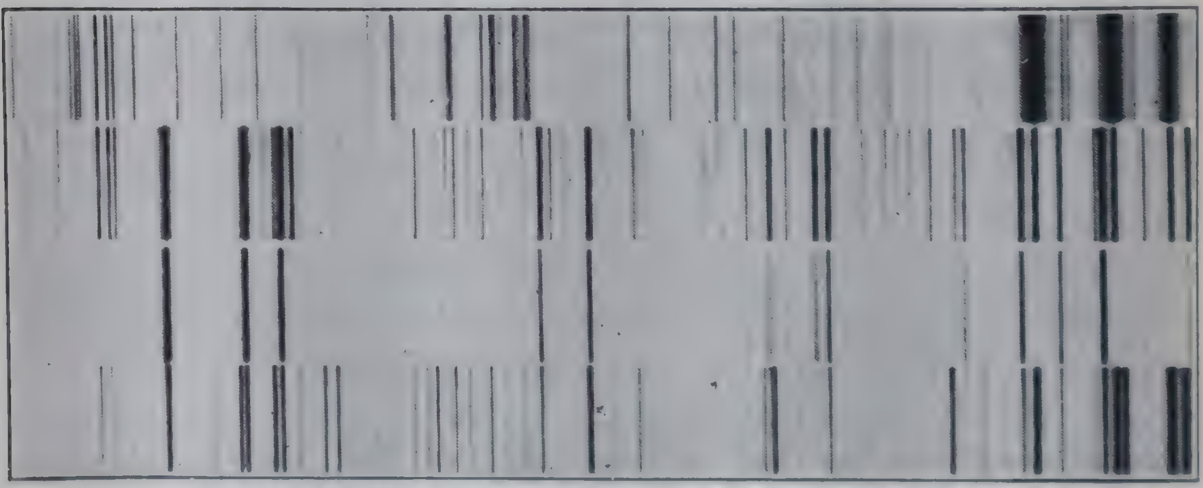


FIG. 12.15*a*. Unknown spectrograms **N**. (See problem 2.)

Problems. 1. In Figs. 12.13 and 12.14 are given examples of the use of the comparison iron spectrum cards in the identification of unknown elements. Indicate the lines and elements present in each of the unknown spectrogram sections shown in these figures.

2. Figures 4.9 and 12.15*a* are connecting portions of the same spectrograms (Fig. 12.15*a* is the higher-wavelength portion and both figures have increasing wavelength values to the right). The three strong lines in the upper spectrogram in Fig. 12.15*a* are the 4254, 4275, and 4290 A lines of chromium. Identify the lines in assigned portions of the spectrograms.

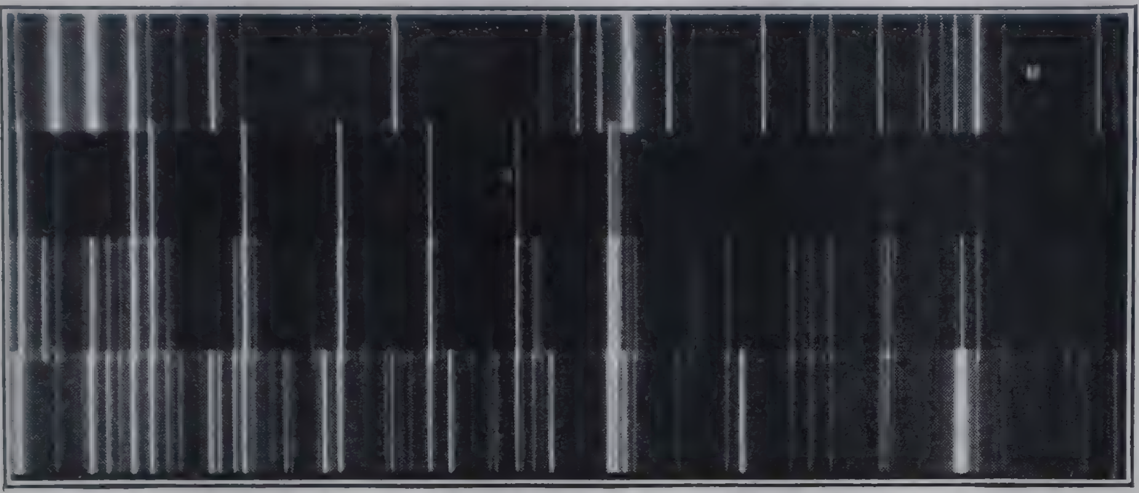


Fig. 12.15*b*. Unknown spectrogram **P**. (See problem **3**.)

3. The second spectrogram (from the top) in Fig. 12.15*b* is of iron with the 3100 A triplet in the center (see Fig. 4.6). Identify the lines in assigned portions of the spectrograms.

EXERCISES 6 AND 7

PREPARATION OF WORKING CURVES AND QUANTITATIVE DETERMINATION OF ELEMENTS BY THE LOGARITHMIC SECTOR METHOD (EXERCISE 6), AND BY THE PHOTOMETRIC METHOD (EXERCISE 7)

The principles involved in this determination are described in detail in the theoretical discussion on the influence of concentration on line intensities (page 93), and the description here will deal only with the application of these principles to the quantitative estimation of elements. It has been shown that for low concentrations of an element the intensity of its spectral lines bears a definite, although not linear, relation to the amount of element present. The measurement of this line intensity is further complicated by the fact that our usual method of recording a spectrum line is by the photographic process, which fails to record all light intensities in a linear density increase (see section on photography, page 357).

Since the two sections of this joint experiment deal with the measurement of line intensities by different methods, it is advisable to use the same set of knowns for both determinations in order that a comparison may be made of the two methods.

Preparation of Samples and Choice of Internal Standard. The preparation of a standard or working curve for use in either of these methods requires a series of samples containing varying known amounts of the "unknown" for which the analysis is to be made, in concentrations extending over the range expected in the samples which may be submitted for analysis. Each of these known "unknown" samples is to contain an added internal standard upon which reference intensity measurements can be made. The amount of this internal standard is to be constant in all samples in the series. Though not necessary in routine analysis it is suggested that two or three internal standards be used with each series in the experiment. The amount of internal standard to be added will depend, of course, on the internal standard lines that are to be used for comparison with the unknown lines and the relative intensities of these lines; i.e., for best results the unknown and standard lines should have about the same intensity in the middle of the range over which analysis is to be made. The photographic tables of Eder and Valenta (*A15*) and those of Gatterer and Junkes (*A26*) are valuable in indicating a choice of possible internal standards to be used with the unknown material. In the tables of spectrum lines according to elements (Tables IV and VI, pages 408 to 594), lines which have been used by various observers for quantitative analysis, together with the lines that have been used as control or internal standard lines, have been indicated by S, B, L, etc.

The conditions involved in the choice of an internal standard and unknown pair as indicated in the section on quantitative analysis require lines whose intensity or intensity ratio does not change with excitation conditions (Fig. 5.2), whose intensity is sufficient for measurement in low concentration of the element, whose wavelength values are reasonably near together, and whose intensity is not appreciably influenced by extraneous elements present in the unknown sample.

It often happens that in commercial laboratories series of chemically analyzed samples containing varying amounts of a number of elements of known concentrations are available. Such series are especially desirable when one wishes to prepare a working curve of metallurgical samples. The choice of a sample depends largely on the nature of the products to which the method is to be applied. If the analysis is to be made of an alloy, then alloy samples should be prepared if possible; if the analysis is to be of a clay or refractory material, then a similar base composition should be chosen for the preparation of the standard samples. In the use of solution samples the standards can be easily prepared by dilution of a basic solution, care being taken that the anions present do not cause partial or complete precipitation of certain of the known or unknown elements. The solutions may be observed with a spark illumination as described by Twyman (Fig. 3.36) (*C195*). If an arc illumination is desirable the solutions may be evaporated in 1-inch cupped pieces of carbon electrodes (Fig. 3.22) and arcked in the usual manner. Powdered samples can be handled very satisfactorily if molded into small briquets or tablets under pressure.

TABLE 12.4

STUDENT SECTION NO.	INTERNAL STANDARD	UNKNOWN
1	Cu, Pb	Ca, Sb, Bi
2	Mg, Zn	Cu, Hg, Pb
3	Cu, Hg	Mg, Zn, Sn
4	Mg, Pb	Ba, K, Cu, Hg
5	Zn, Sn	Pb, Cu, Mg
6	Mg, Bi	Zn, Cu, Ca

The preparation of standard samples for a clay or refractory series is somewhat more difficult but the exposure technique is simpler, and hence this is recommended as a laboratory experimental procedure to observe and compare methods. The same procedure has been found to work in the preparation of working curves of solutions. In a group of thirty or forty students the class is usually subdivided for convenience into five or six sections and each group prepares its own series of samples. Table 12.4 indicates possible combinations of elements for comparison studies and construction of working curves for quantitative analysis.

For each student section there are to be eight unknown samples, one standard (containing the internal standard only), and one blank sample (basic compound), as indicated in Table 12.5. In the method of preparation indicated in this table it will be noted that about 200 grams of No. 2 (basic compound + internal standard) are required and that in the end one has available about 20 grams of each sample for analysis purposes. (If a solution method is used a corresponding number of milliliters will be required.) A satisfactory basic compound for this experiment is a mixture of 25 parts of silicic acid (anhydrous) and 100 parts of alumina (Al_2O_3) ground together in a ball mill to produce a fine free-flowing powder.

TABLE 12.5

PREPARATION OF SAMPLES

Sample No.	% Internal Standard	% Unknown	Method of Preparation
1 (Blank)	None	None	Basic Compound
2 (Standard)	1.0	None	1% of each internal standard
3	1.0	0.001	23.3 g No. 2 + 10 g No. 4
4	1.0	0.00333	20 g No. 2 + 10 g No. 5
5	1.0	0.01	23.3 g No. 2 + 10 g No. 6
6	1.0	0.0333	20 g No. 2 + 10 g No. 7
7	1.0	0.1	23.3 g No. 2 + 10 g No. 8
8	1.0	0.333	20 g No. 2 + 10 g No. 9
9	1.0	1.0	23.3 g No. 2 + 10 g No. 10
10	1.0	3.333	3.3% of Each Unknown in No. 2

Note: Concentration of cations as given in percentages applies to the free element. In the preparation of samples 2 and 10 allowance must be made for anions such as the hydroxide or carbonate in determining the percentage of elements introduced.

In the preparation of some of these standard and unknown mixtures, solutions have been made of the metal ions and added to the clay together with sufficient water to form a mush; the mixture is dried in an evaporating dish on a steam plate with constant stirring and then ground in a mortar or ball mill to insure uniform distribution of the metal ions.

To shorten this preparation a modification has been tried, with reasonable success, in the grinding of the metal salts (preferably as the carbonates) with a small amount of the silica-alumina mixture (sample 1) and then grinding this with the remainder of the mixture required for the sample. The final 30 grams of the mixture is to be sampled by the "quartering process" used in analytical methods, and 10 grams of this is to be set aside for the preparation of the next mixture.

Although the experience of preparation of a series of standard samples for the determination of the working curve may be of some advantage in the teaching of laboratory technique, many students may not have sufficient time available and hence it is suggested that such students be provided with a series of prepared samples. It is obvious that the supplying of a series of prepared samples is necessary if the unknowns are to be a series of metal alloys such as steels. By selection from a series of analyzed samples of commercial products, a satisfactory series of such metals or alloys for the preparation of working curves can usually be obtained. It will probably be necessary in the study of these samples to use a line of the principal element as the internal standard or control line.

Experimental Procedure—Slit Illumination. In making photographs with the logarithmic sector a cupped electrode is to be used, and 10 exposures of 6 to 10 seconds each are made, refilling the electrode each time, thus making an exposure of 1 to 2 minutes for each sample. The first series of photographic exposures are to be made with a logarithmic sector in accordance with the method of Scheibe (*A81*). This method requires that the sector be placed as near the slit as possible and that the slit be illuminated as uniformly as possible. For this uniform illumination one can best use a long-focus lens immediately in front of the sector (Fig. 12.16). This long-focus lens should bring the arc or spark to a focus on the collimating lens of the spectrograph, where a suitable diaphragm can be placed so as to cut out unwanted electrode portions of the arc or spark. If the light source is located at a distance from the lens, sector, and slit of about 30 to 50 cm and the distance from the slit to the collimating lens is this distance or greater, it is obvious that the position of the arc or spark must be carefully set and watched on the test screen during the exposure so as to be sure that the diaphragm in front of the collimating lens in the spectrograph is properly filled. If there is some uncertainty about the filling of this diaphragm and the spectrograph is easily opened for inspection it is worth while to open the slit to about 1 mm, illuminate the slit with the light source, and examine the image of the source on a white card placed in front of the collimating lens. One should, of course, be careful to close the spectrograph and

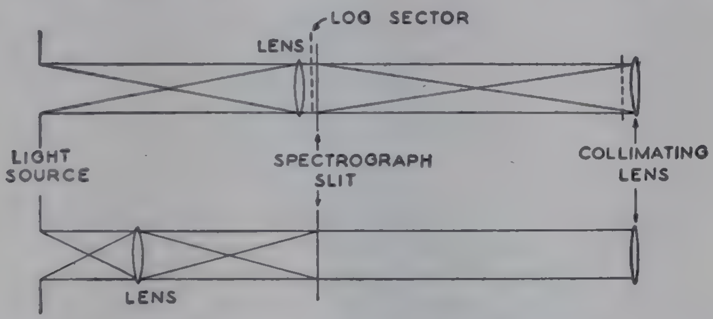


FIG. 12.16. Position of slit illuminating lens. *a*. Slit wedge or logarithmic sector method. *b*. Normal use.

reduce the width of the slit before opening the plate holder and proceeding with the observations.

Logarithmic Sector Exposures. It is essential in the use of a logarithmic sector (Fig. 5.4) that the cutting or straight edge of the sector be parallel with the slit at the moment at which it crosses the slit. The sector can be driven by a small synchronous motor such as the motor of an electric clock. In the use of the sector method it is usually necessary to remove the Hartmann or wedge diaphragm in front of the slit. In order to photograph the normal spectrum of iron as a comparison, on the lower edge of a logarithmic sector photograph, it is necessary to stop the sector, move the plate holder about 2 mm upwards (assuming that the sector is set so that its center of rotation is below the slit), and set the sector

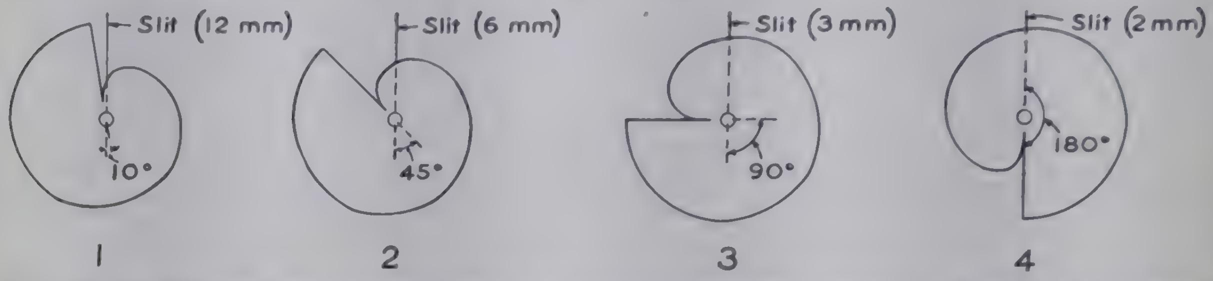


FIG. 12.17. Slit and sector positions for stopped sector photograph (height of slit and spectrogram indicated in millimeters, based on a 15-mm maximum slit length).

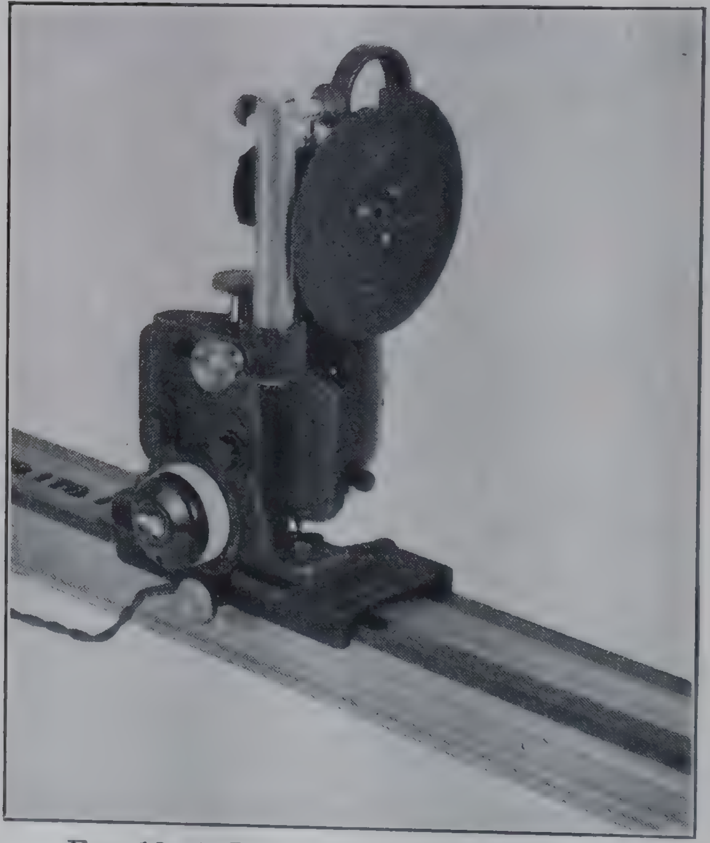


FIG. 12.18. Logarithmic sector (Hilger).

so that it makes an angle of about 90° to 180° with the slit (Fig. 12.17). This will produce a narrow spectrogram of about 2 mm below and in contact with the logarithmic sector spectrogram.

Since the logarithmic sector method uses the full slit aperture, the spacing between photographs will have to be 15 mm. To be sure of the purity of the electrode a photograph should first be made with the carbon electrode; then a photograph should be made of the silica-alumina mixture to determine what elements may be present in this mixture. The third photograph is to be a standard, such as the silica-alumina mixture plus the internal standard but without any of the unknown elements. After this the mixtures containing the "unknown" should be exposed, starting with the mixture containing the smallest amount and proceeding to samples with higher concentrations of the unknown. By following this order of exposures it is not necessary to use new carbons for each exposure, although this would be done, of course, if one were working with substances of unknown concentration or preparing a working curve for exact quantitative analysis.

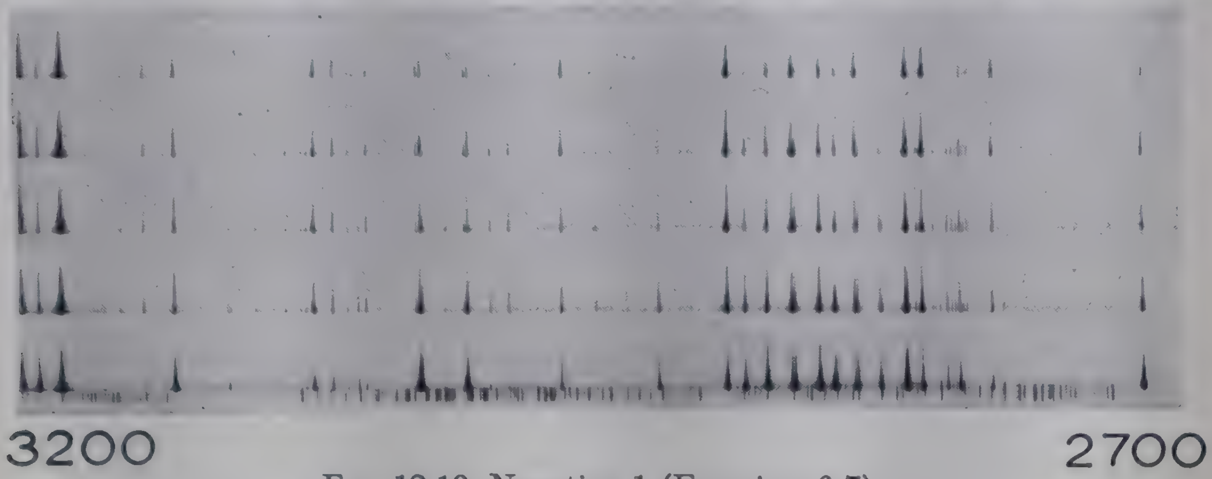


Fig. 12.19. Negative 1 (Exercises 6-7).

The carbon blank on the first negative should be taken at 0 mm on the plate position scale, the silica-alumina at 10 mm, and the remaining four exposures on this negative at 15-mm intervals. The sector should now be stopped and set at 90° to the slit (see Fig. 12.17). The plate holder should be moved to 72 and a 10-second iron spectrum taken.

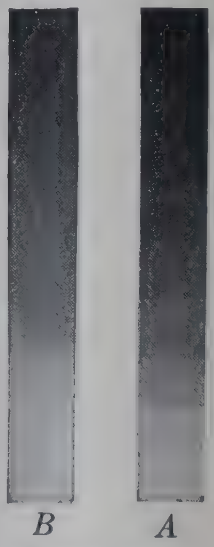


Fig. 12.20. Step-density wedge (*A*). Log-density wedge (*B*).

The second negative will start with sample 6 and continue at 15-mm intervals to sample 10. The revolving logarithmic sector is again to be stopped and this time set to an angle of 45°, the plate holder advanced 5 mm from the previous photograph, and another 10-

second iron spectrum taken. Slit width on both negatives should be 0.03 to 0.05 mm.

Photometric Exposures. Continuing on the same negative, the photometric-method exposures may be recorded by making 6 exposures of about 6 seconds each with the electrode refilled before each exposure. For these photographs the sector should be stopped and set at about 45° and the plate holder moved 5 mm after each sample photograph. Starting with new carbon electrodes, the silica-alumina mixture, the blank with the internal standard, and the samples in the order of increasing concentration are to be photographed. After the last sample an iron spectrum should be taken, making 12 photographs in all.

Application of Density Pattern. Before these plates are developed they should be calibrated by having a density wedge (Fig. 12.20) printed on them. For student demonstration a logarithmic density negative can be placed on the top of a printing box so that the low-wavelength edge of the plate can be exposed. The time of flashing or exposing the density pattern should be such as to yield a gradation from opaque to transparent in the range of the wedge, after the negative has been developed. Another method of applying a density pattern is to make a series of separate exposures, each of an area sufficient to fill the slit in front of the photocell when projected through the densitometer to vary at a logarithmic rate, and the exposures to be made from a light source of constant intensity. In both the above methods for plate calibration the $d/\log I$ curve will be that of the wavelength of light emitted by the exposing light rather than that of the wavelength of the spectrum line with which it is compared. Although there is some variation between these two curves (see Fig. 5.15) the similarity of the two will be sufficient for the student observation.

A more satisfactory and accurate method of plate calibration, and that used in routine analysis, can be obtained through the use of a step wedge, or step sector in front of the slit, or a step slit (*C74*). By this method a density pattern can be obtained for the negative at the same, or approximately the same, wavelength as that at which the analysis observations are to be made. For this calibration a sector with four or five steps is satisfactory. The exposure time should be adjusted so that the density of the lowest step will be about 0.05. (For more detailed instructions see Pierce and Nachtrieb (*C162a*.)

Number of Negatives. The above series of photographs if made on a Littrow instrument should be made first at the setting of the spectrograph which includes the 3000–4000 A region, and then repeated at the setting which includes the 2500–3000 A region. In all, four plates are to be prepared for this exercise.

Measurement of Line Intensity—Logarithmic Sector Method. Each student will be assigned one unknown element to be compared with one of the internal standards. It may be necessary to use several lines of either the known or internal standard before a satisfactory series can be located. The choice of line pairs has been discussed in an earlier chapter.

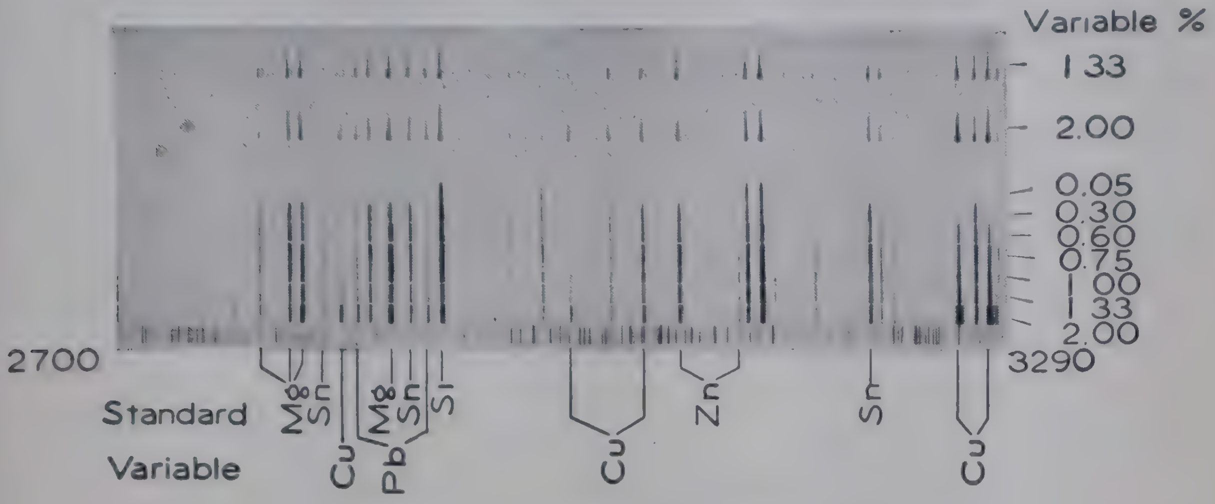


FIG. 12.21. Negative 2 (Exercise 6-7).

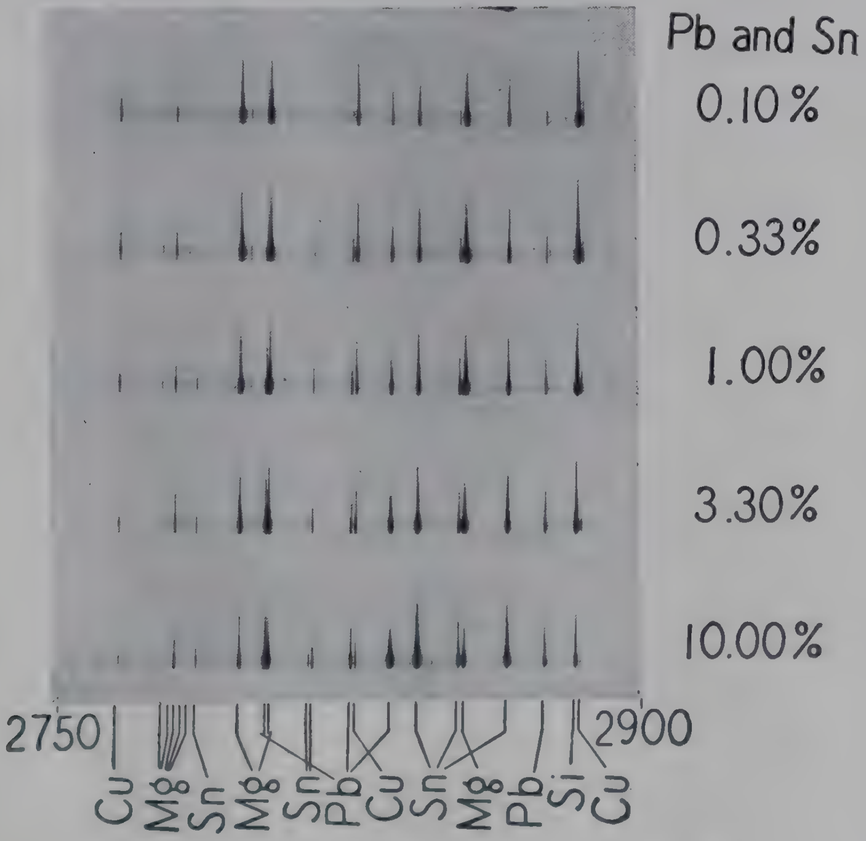


FIG. 12.22. Enlarged section of Fig. 12.19.

The lines by the logarithmic sector method (Fig. 12.22) are to be measured to the nearest 0.1 mm by a graduated eyepiece. The measurement to be made is the length of the line from its end to the dark strip caused by the outer edge of the sector. A record (Table 12.6) should be kept of the observed line lengths, and the difference between the lengths of the known and standard plotted (Figs. 12.23 and 12.24) against the concentration in percentage and against the concentration in log percentage. In the latter case a straight line should be obtained, at least over the effective portion of the concentration range.

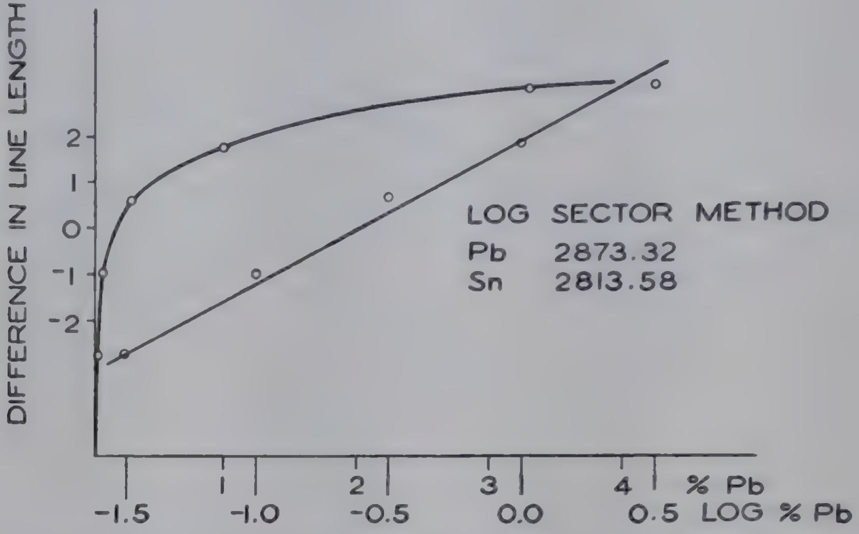


FIG. 12.23. Logarithmic sector working curve.

Measurement of Line Intensity—Photometric Method. The series of spectrograms taken with the stationary sector (45° angle) so as to yield a line height of about 4 mm are to be measured by means of a densitometer. Any one of the available commercial instruments will prove quite satisfactory for this experiment, or a photometer may be improvised through the use of a projection system such as is available in a

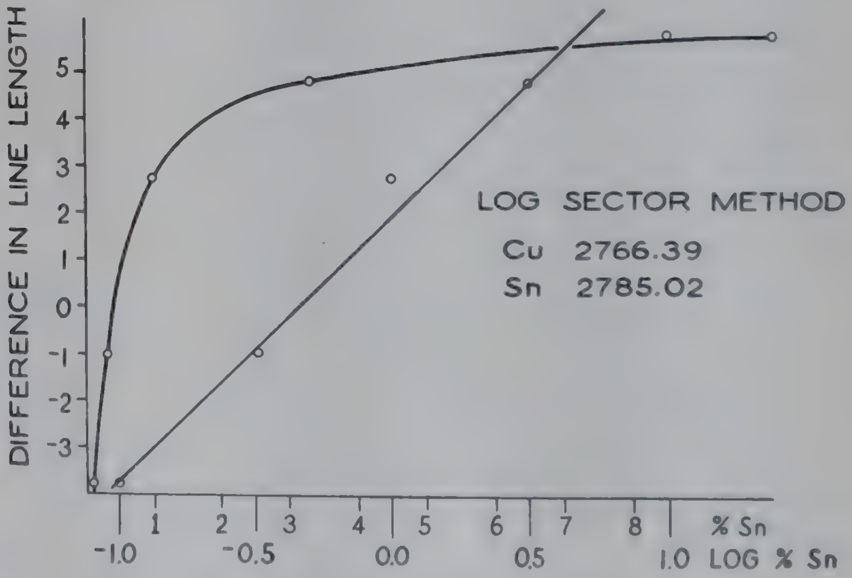


FIG. 12.24. Logarithmic sector working curve.

lantern-slide projector. The spectrum image is projected on a screen in which has been placed a slit with a photocell backing it (Fig. 12.25). The current from the photocell (*A23*) can be measured by a galvanometer or sensitive microammeter, thus providing a measure of the line density. It is desirable to use a mechanical drive on the plate motion and to observe the maximum swing of the galvanometer as the spectrum line passes in front of the slit; this is not necessary, however, and accurate results can be obtained from careful setting of the spectrum line in front of the slit by manual operation.

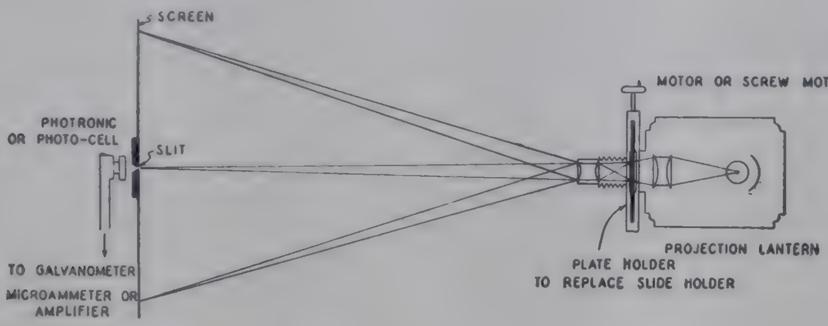

SCREEN
MOTOR OR SCREW MOTION
PHOTRONIC OR PHOTO-CELL
SLIT
PROJECTION LANTERN
PLATE HOLDER TO REPLACE SLIDE HOLDER
TO GALVANOMETER MICROAMMETER OR AMPLIFIER

FIG. 12.25. Spectrum plate densitometer.

The observer should record the density (Table 12.6) of the unknown and internal standard lines in each of the spectrograms as indicated by the galvanometer readings. The observer should also record the galvanometer readings for a clear portion of the plate, the zero light intensity reading with the photronic cell covered, and the density values of the plate calibration lines or areas. The logarithm of the ratio of the deflection values of standard and unknown lines should be plotted against the concentration and log concentration of the unknown line (Fig. 5.21). Since over a considerable portion of the plate density there is a linear relation between the density and the logarithm of the exposure or the logarithm of the intensity, this density difference should be equivalent to the difference in line length obtained by the logarithmic sector method.

The procedure for determining the line intensity ratio from the galvanometer deflection can be simplified if an optical diaphragm is applied in the optical path or a potentiometer bridge is placed in the electrical circuit so as to produce a galvanometer swing of 100 for the clear portion and zero for an opaque portion. In some instruments absorption rather than transmission is observed by setting the 100 at opaque and the zero deflection at transparent. The per cent transmission can be converted to relative intensity by means of an emulsion calibration curve.

In the conversion of the per cent transmission of the internal standard and unknown lines into relative intensity, the per cent transmission of

TABLE 12.6

(Form of Report of Data in Exercises 6 and 7)

Spectrographic Laboratory

Report on Working Curve Data

Observer....................	QUANTITATIVE	Plate No............................
Date........................	SPECTROGRAPHIC	Method and Settings.................
Internal Standard *Pb 2833.07*	ANALYSIS	*Base Material--*$Al_2O_3 = 20\%$;
Unknown *Bi 3067.73*		$H_2SiO_3 = 80\%$

	Concentrations			Log Sector Method Length of Lines Ratio			Densitometer Method Deflection		Densitometer Method Background	Ratio	Log Ratio
No.	*Pb%*	*Bi%*	*Log Bi%*	*Bi 3067.73*	*Pb 2833.07*	*Bi—Pb*	*Bi 3067.73*	*Pb 2833.07*	ground	(I_{Bi}/I_{Pb})	(I_{Bi}/I_{Pb})
1	...	...	.....	...	..	..	.....	.....	*95*	...	.....
2	*1.00*	...	.....	...	*7.0*	..	.....	*18 (48)*	*93*	...	.....
3	*1.00*	*0.01*	*−2.00*	*5.2*	*7.2*	*−2.0*	*82 (99)**	*18 (49)*	*92*	*0.09*	*−2.97*
4	*1.00*	*0.02*	*−2.30*	*6.3*	*7.2*	*−0.9*	*78 (98)*	*18 (50)*	*92*	*0.17*	*−1.23*
5	*1.00*	*0.03*	*−2.47*	*7.2*	*6.8*	*0.4*	*71 (97)*	*18 (49)*	*93*	*0.24*	*−1.38*
6	*1.00*	*0.04*	*−2.60*	*9.3*	*7.8*	*1.5*	*63 (95)*	*18 (48)*	*92*	*0.42*	*−1.63*
7	*1.00*	*0.05*	*−2.70*	*9.2*	*7.0*	*1.9*	*36 (79)*	*18 (48)*	*91*	*0.68*	*−1.83*
8	*1.00*	*0.06*	*−2.78*	*10.6*	*7.5*	*2.8*	*25 (60)*	*18 (49)*	*92*	*0.87*	*−1.94*
9	*1.00*	*0.07*	*−2.84*	*11.2*	*7.4*	*3.1*	*18 (47)*	*18 (48)*	*93*	*1.02*	*0.01*
10	*1.00*	*0.08*	*−2.90*	*11.7*	*6.9*	*4.8*	*16 (42)*	*18 (49)*	*92*	*1.09*	*0.04*

*Numbers in parentheses are deflection values corrected for background.

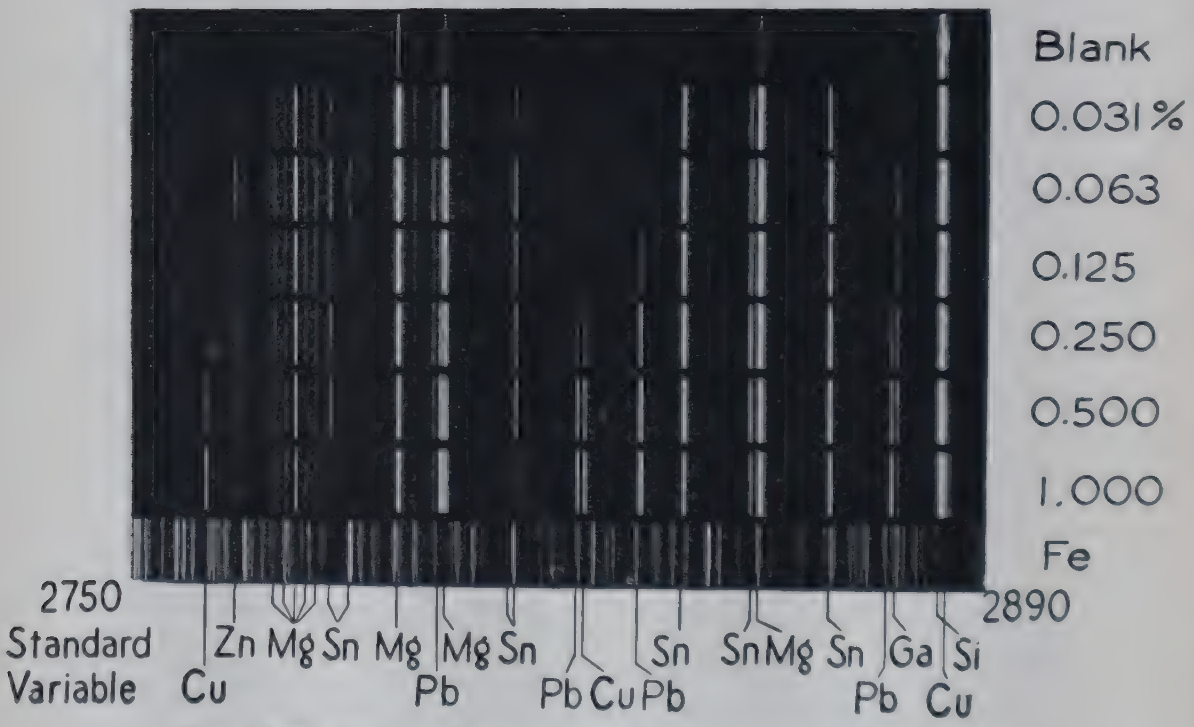


Fig. 12.26. Enlarged section of densitometer negative. P.

the internal standard line is extended on the log per cent transmission/log intensity curve (see Figs. 5.13 and 5.22) and the ratio of the intensities read from the intensity scale by shifting the unity value of the scale to the extended intercept of the internal standard transmission/intensity value. For a specific element a factor may be determined from working curves prepared from known samples (plotting intensity ratio vs. per cent of element, Fig. 5.11, and observing the per cent equivalent to unit ratio of intensity). This factor may be used as the setting of the log intensity scale (Fig. 5.22) and the per cent of elemental concentration read directly.

In this exercise the ratio of the intensities of internal standard and unknown element lines is to be determined from the emulsion calibration curve and these ratio data are to be plotted (1) on a linear scale against linear per cent composition of the "unknown" element and (2) on a log of the intensity ratio against log per cent composition of the unknown element.

It should be noted that linear effects should be obtained in both these systems of recording working curves, but that in the case of the log of line intensity ratio/log of per cent composition a 45° slope is obtained and that for different line combinations parallel lines will be obtained (Fig. 5.11). Self-absorption will result in curvature of the upper end while background effects will cause a toe at lower intensity values (Fig. 5.13). On the linear intensity ratio/per cent composition system of reading the working curve, all true curves will pass the zero ordinate and different line pairs will have different slopes.

The emulsion calibration curve (see page 110 and Chapter XIII) should be determined for the wavelength region assigned for the analysis exercise. A three- or four-step sector or multiple absorption wedge should be used in front of the spectrograph slit, in which each step transmits twice that of the next lower step. Using an iron arc or spark as the emitting source, a spectrogram with these steps is to be included in the spectrographic data. The per cent transmission of two or more steps of a number of iron lines of varied density is to be observed in the selected spectral region.

Choosing from these transmission data a group of densities of a single line of average density the data are to be plotted on a log per cent transmission/log intensity scale (log/log paper is quite suitable for this purpose, or a log scale such as that obtained by use of the slide section of a slide rule as a ruler). Since the lower transmission portion of this calibration curve will be linear, one may draw a line through these lower values and then locate on this line the transmission value for the intermediate value obtained from another iron line. Set the extension of the intercept of this transmission value and the line obtained from the first set of values as any integer value on the log scale on the intensity axis. The multiple transmission values are plotted at the corresponding multiple intervals on the log scale.

For example, the data observed on two iron lines gave deflection (per cent transmission) of 80, 30, 5.5, 1.25; and 92, 50, 9, 2 for steps with opening equivalent to 1, 2, 4, and 8. The first of these deflection values are plotted on a log scale against a log scale of 1, 2, 4, and 8. The second set of data (95, 50, 9, 2) are now plotted by locating the 9 transmission value on the curve or line produced from the first data, and setting the lower intensity scale at an integral value such as 2. The transmission values for the other steps (95, 50, 2) are plotted at the corresponding multiple values on the log scale (½, 1, and 4), and the repetition of the process for data for several lines of varied intensity will provide a suitable calibration curve. The slope of this calibration curve in its linear portion is expressed as the tangent of the angle produced with the horizontal axis and is known as gamma (see Chapter XIII).

If the transmission values for a group of iron lines covering a considerable wavelength range do not form a single smooth curve, it will be necessary to limit the analytical range to that portion for which a single gamma curve applies or to correct for this variation of gamma with wavelength (Fig. 5.15). There are some emulsions which possess a nearly uniform gamma over the available photographic range (such as Eastman "par-speed" film).

Background Correction. Since background represents an added intensity to the line, the correction for it is made by subtracting the intensity of the background from the intensity of the line (Fig. 5.12). The ratio of the corrected intensity values is then applied to the working curve (Fig. 5.11) to determine the per cent composition.

An alternative method of correction may be effected by setting the background transmission value on a log scale (Fig. 5.13) as equivalent to unity on the sliding intensity scale and observing the intensity of the line plus background on this scale. Since the background has been set at unit intensity, the intensity or the line less background intensity will be equal to the observed line intensity minus one. The corresponding transmission for the corrected intensity can be determined from the transmission producing the corrected intensity on the sliding scale. Double sliding scales and calculating boards have been devised to permit correction for background, gamma, and elemental factors so that corrected elemental composition may be read directly.

Report on Exercise 6. The report to be handed in for Exercise 6 (logarithmic sector method) should include: (1) a data sheet indicating the composition of the samples and observed line lengths and differences (see Table 12.6); (2) a curve indicating the relation between line length difference (relative intensity) and percentage composition; and (3) a similar curve indicating log percentage composition.

Report on Exercise 7. In the report which is to be handed in for Exercise 7 (the photometer method) there should be: (1) a data sheet indicating the composition of the samples and galvanometer readings for the samples and log ratio of the line intensities (see Table 12.6); (2) a *d*/log *I* curve for the photographic plate based on the log intensity ratio (this may be omitted if the data are supplied by the instructor rather than observed); (3) a curve of the unknown-standard intensity ratios plotted against percentage composition; and (4) a curve of the log percentage composition-log intensity ratio.

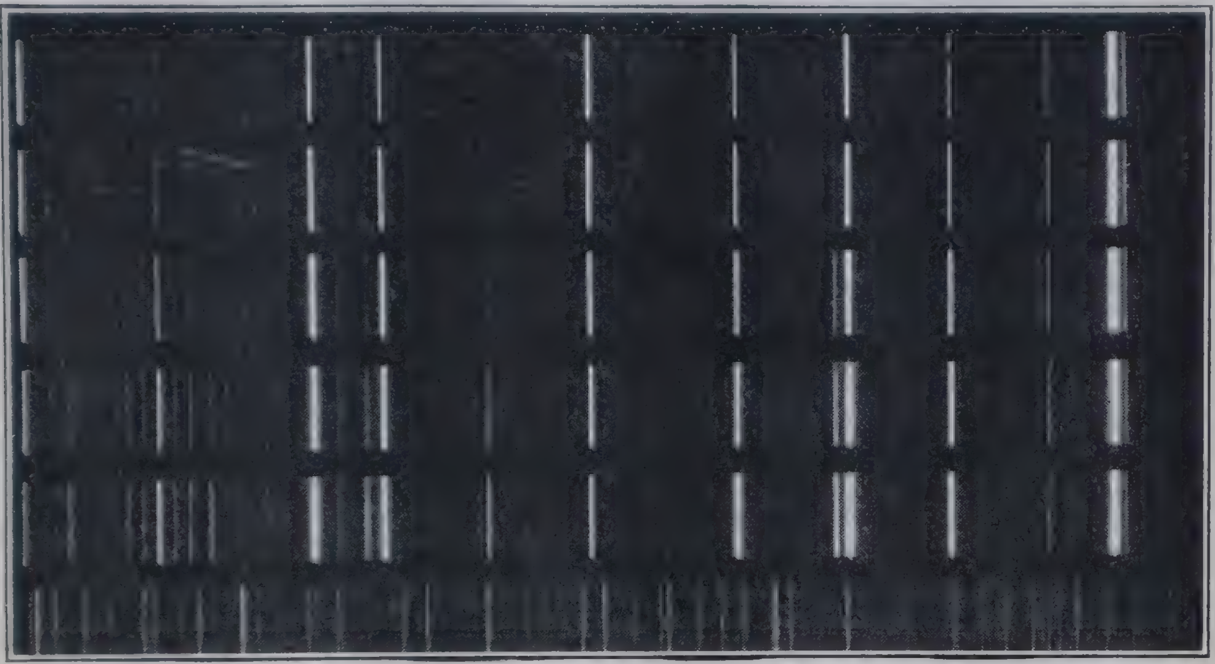


FIG. 12.27. Portion of a spectrogram for preparation of a quantitative working curve. **P.**

Remarks. A convenient method of constructing a logarithimc or step sector is to draw on a piece of polar coordinate paper an accurate circular logarithm or step curve. A thin aluminum disk of the proper size is cut and drilled to the exact size of hole required to fit on the bearing shaft, which may be attached to the spectrograph. The disk is cut to approximately the same relative size and curvature as the drawing would indicate, although the disk will be about one-tenth the diameter. The disk is then placed on a glass plate in the holder of the enlarging machine, and the enlarging machine is focused to give almost the same degree of enlargement as the polar coordinate drawing, centering the hole in the disk on the center of the polar coordinate sheet. One can tell from this enlargement the exact places on the disk where it is necessary to cut or file and the amount of such reduction required. The process of cutting and smoothing down must be continued until a perfect miniature reproduction of the paper curve is produced in the sector.

The pairs of spectrum lines used in the logarithmic sector method should be used in the photometric method, so as to provide a comparison of the two methods.

Problems. 1. Plot the logarithmic sector and the densitometric working curves for which the data are supplied in Table 12.6.

2. Plot the logarithmic sector and the densitometric working curves for which the data are supplied in Table 5.4.

3. Identify the 2833 Pb line and the 2779 Mg line in Fig. 12.22. Measure the length of these lines, and plot the working curve.

4. The observed galvanometer data as obtained in the examination of a spectrogram of an aluminum containing sample (with molybdenum as an internal standard) are as follows:

Deflection (dark field) = 150
Deflection (clear) = 10
Deflection of standard line (Mo 2816 A) = 125
Deflection of Al line (Al 3082 A) = 55

From the data on the plate calibration (Figs. 5.12 and 5.13) and the working curve for the Al 3082/Mo 2816 intensity ratio (Fig. 5.11), calculate the percentage of Al in the sample.

5. Identify the variable and standard elements in the densitometer series reproduced in Fig. 12.27.

6. If correction for background was not required in the data used in the report on Exercise 7, indicate the change in the per cent composition/intensity ratio curve if all the observed data had been made with a background transmission of 60 per cent. (Discard data of greater than 60 per cent transmission in making these calculations.)

7. In the analysis of materials containing relatively high and constant concentrations of certain elements it is often convenient to use a weaker line of one of these principal constituents as the internal standard (i.e., iron lines in steel analysis or aluminum lines in aluminum alloys). Indicate the change which would take place in the working curves (both log ratio/log concentration and ratio concentration) when the unknown per cent concentration is increased to approach 100 per cent.

VISUAL ABSORPTION SPECTRA DETERMINATION OF GLASS AND SOLUTION SAMPLES

The object of this experiment is to determine the visual absorption spectra of certain colored samples. These determinations may be made on a visual spectrophotometer such as the Bausch and Lomb, Hilger-Nutting, Keuffel and Esser, or König-Martens. The Bausch and Lomb apparatus (Fig. 12.28) is equipped with a colorimeter type of cell holder (Fig. 7.19) which permits the measurement of the transmission of liquids of any desired thickness up to 6 cm. The instrument is designed so that the colored sample may be placed in front of either of the beams, but, in order to get positive readings on the observation scale, the colored samples should be placed in the right-hand beam.

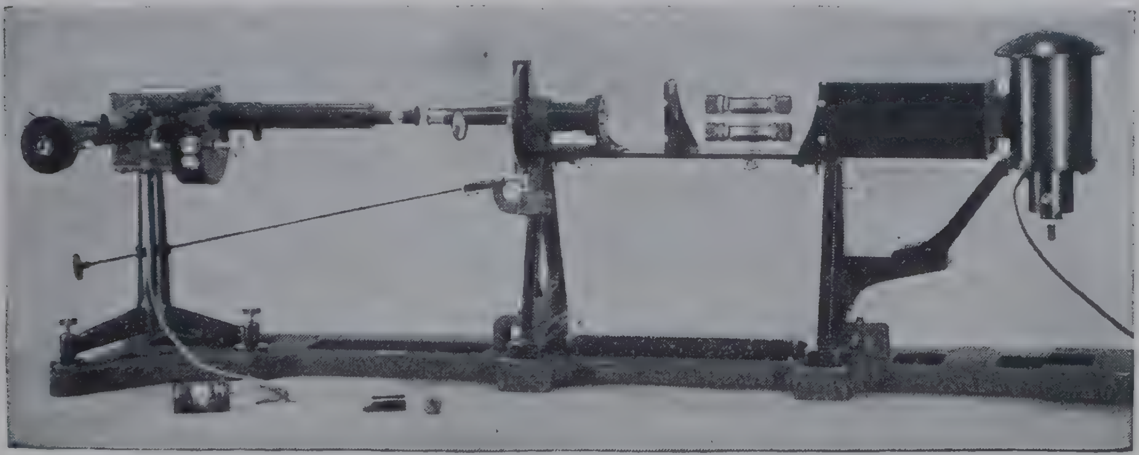


Fig. 12.28. Spectrophotometer (Bausch and Lomb). (See Fig. 7.19 for diagram.)

Determination of Match Point. No adjustment should be necessary, but it is advisable to observe the spectrum with both beams clear and to check whether extinction values remain zero over the spectral range. Two observations for each point to be plotted are made, i.e., one must observe the wavelength value and the extinction value. The match is observed in the eyepiece as a column of light, differing in color in accordance with the wavelength which is being observed, and divided across the center into upper and lower segments. A change of the extinction will, of course, alter the relative intensities of the two halves (Fig. 12.29). The width of the column or slit of light can usually be adjusted, and it should be set to as narrow a column as can be observed conveniently. The eyepiece itself can be focused by the focusing screw which is on the tube leading to the prism unit. In using the Bausch and Lomb instrument, care should be taken not to disturb the small screw by the eyepiece. This is *not* a focusing screw but determines the wavelength calibration of the instrument.

Photometer Scale. On the Hilger instrument the graduated photometer disk is divided in densities and degrees, the König-Martens and Gaertner instruments are graduated in a similar manner, and the Keuffel and Esser instrument is graduated in percentage of light transmitted. The Bausch and Lomb instrument has the photometer scale divided into three parts: one part, involving an angular swing of 180°, is graduated in degrees; the remaining two parts of 90° each are graduated (*a*) in percentage transmitted, and (*b*) in the negative logarithm of the percentage transmitted, or, as commonly known, the extinction coefficient. (See Table XI for interconversion of these units.) In making observations, extreme care should be taken that the readings are made on the same scale, and not part on one and part on another, since the match points are observable on any of the scales. From a point of efficiency the best extinction values are observable from 0.5 to 1.8, and, if a solution is being used, the cell thickness should be altered to provide extinction values within these ranges.

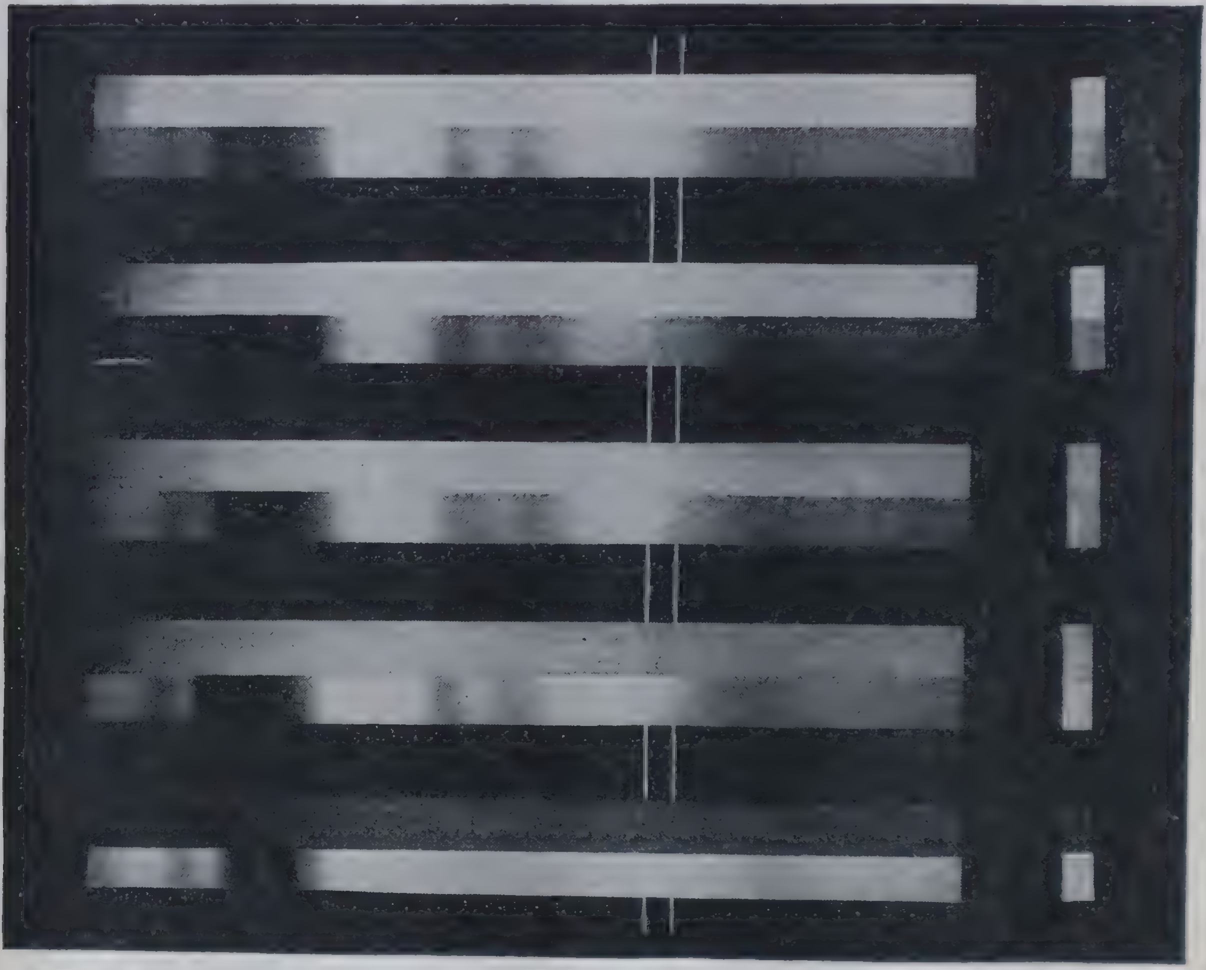


FIG. 12.29. Match point and slit opening; strips indicate appearance of spectra at different extinction settings of comparison beam, with wide (left) and narrow (right) ocular slit.

Method of Observation. Data obtained for the test samples should be recorded on the data sheets and graph paper provided for this purpose (Figs. 12.30 and 12.31). It is advisable to make at least two readings per setting, and to make these rapidly (one or two seconds for each reading) rather than spending considerable time in trying to arrive at a satisfactory match point. If, with the slit of the eyepiece open, there appears to be no component structure in the observed sample, the readings should be made every 10 mμ; but if there is a component structure such as is observable in a neodymium glass the readings should be made at least every 5 mμ. Observations should not be attempted beyond 450 mμ in the blue or 720 mμ in the red. In the determination of absorption spectrum curves by a spectrophotometer it is suggested that the wavelength drum be set at definite values as indicated (Fig. 12.31) and the extinction adjusted to a match point, except for very sharp bands when it may become desirable to set the extinction to definite values, say every 0.1 or 0.05 E, and change the wavelength to obtain a match point.

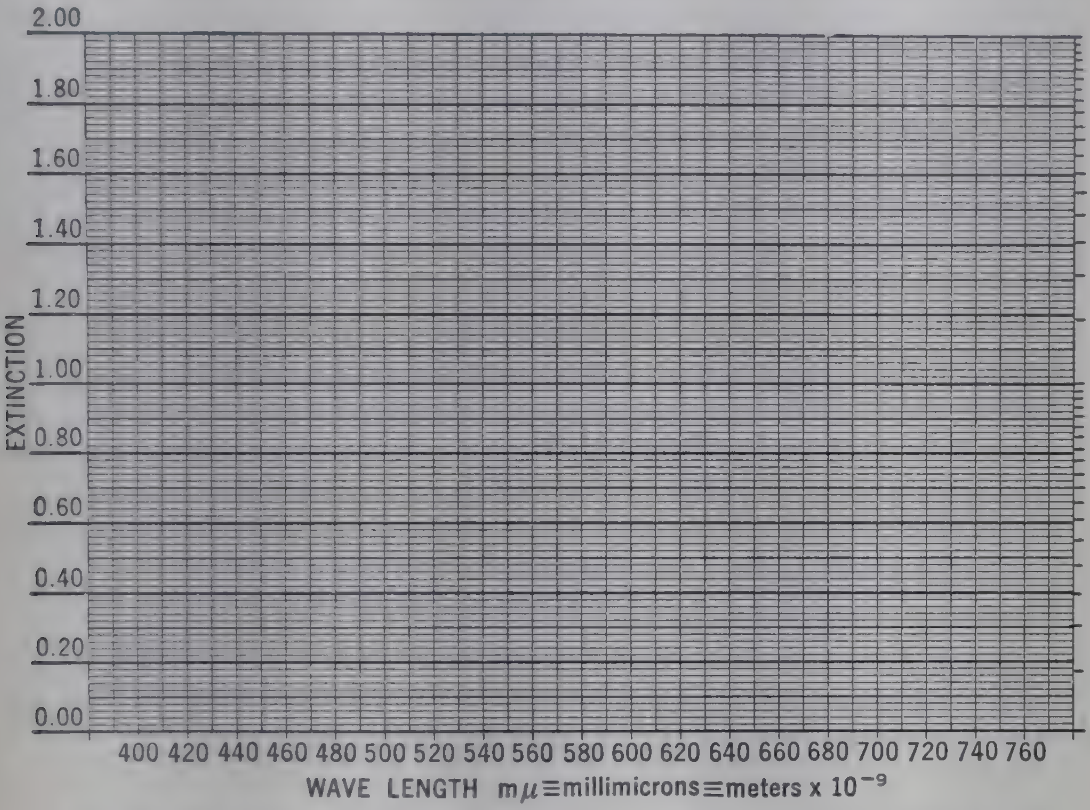


Fig. 12.30. Form for graphical recording of spectrophotometric data.

The dispersion drum of the spectrometer can be obtained with frequency rather than wavelength graduations, should the operator desire to record his data principally in frequency values. If a record sheet similar to the sample (Fig. 12.31) is used it will be noted that frequency values (in fresnel units) are given in italic type in parentheses below the wavelength values, so that curves may be plotted directly from the data

Fig. 12.31

SPECTROGRAPHIC LABORATORY No. . . . .

VISUAL SPECTROPHOTOMETRIC ANALYSIS

Sample (1) . . . . Conc. . . . . Sol. No. . . . . Observer. . . . .

(2) . . . . Conc. . . . . Sol. No. . . . . Date. . . . .

Solvent (1) . . . . (2) . . . . (UV. Plate No. . . . .)

	(1)		(2)			(1)		(2)	
	Cell	cm	Cell	cm		Cell	cm	Cell	cm
	Extinction	Av.	Extinction	Av.		Extinction	Av.	Extinction	Av.
440					590				
(682)	———	—	———	—	*(509)*	———	—	———	—
450					600				
(667)	———	—	———	—	*(500)*	———	—	———	—
460					610				
(652)	———	—	———	—	*(492)*	———	—	———	—
470					620				
(638)	———	—	———	—	*(484)*	———	—	———	—
480					630				
(625)	———	—	———	—	*(476)*	———	—	———	—
490					640				
(612)	———	—	———	—	*(469)*	———	—	———	—
500					650				
(600)	———	—	———	—	*(462)*	———	—	———	—
510					660				
(588)	———	—	———	—	*(455)*	———	—	———	—
520					670				
(577)	———	—	———	—	*(448)*	———	—	———	—
530					680				
(566)	———	—	———	—	*(441)*	———	—	———	—
540					690				
(556)	———	—	———	—	*(435)*	———	—	———	—
550					700				
(546)	———	—	———	—	*(429)*	———	—	———	—
560					710				
(536)	———	—	———	—	*(423)*	———	—	———	—
570					720				
(526)	———	—	———	—	*(417)*	———	—	———	—
580					730				
(517)	———	—	———	—	*(411)*	———	—	———	—

sheet in either abscissa. It is highly desirable to plot the absorption spectrum curve while the sample is in the instrument and to examine the curve for apparent irregularities. These irregular points on the curve should be rechecked on the instrument to determine whether an error in reading has been made or whether the curve actually has an irregular shape.

Experimental Procedure. In this exercise the following observations, or such portions as the instructor may indicate, should be made.

1. Absorption spectra of cobalt, nickel, or other simple colored glass. (See Fig. 11.9.)

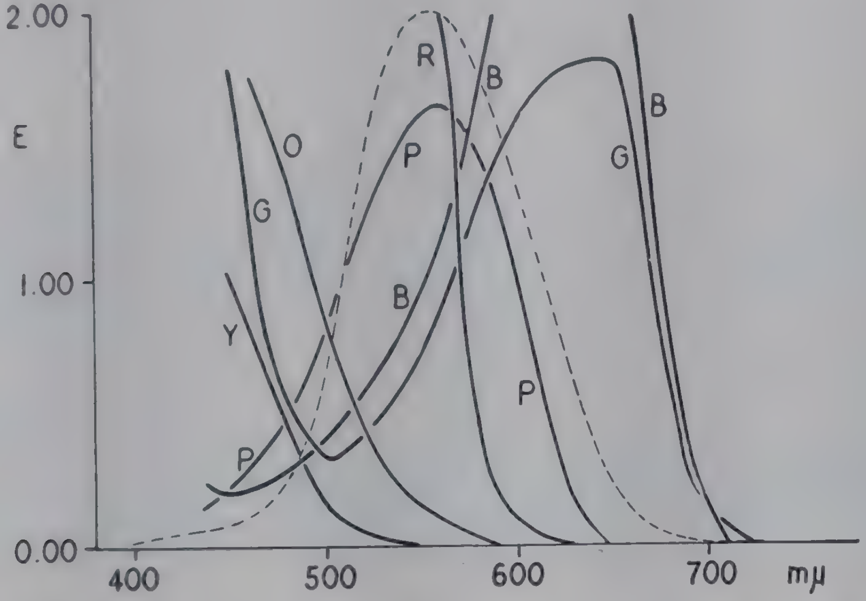


FIG. 12.32. Absorption spectra curves of colored Cellophane films. (See Figs. 12.44 and 12.45.) Yellow (Y), orange (O), red (R), green (G), blue (B), purple (P). (Dotted curve indicates relative visibility.)

2. Absorption spectrum of neodymium glass.
3. Absorption spectrum of a dye solution (crystal violet).
4. Absorption spectrum of a potassium permanganate solution. If the use of the apparatus is limited, it is suggested that samples 2 and 3 be selected. The colored solutions should be adjusted in concentration so as to give a maximum extinction value of about 2.0 E for the cell thickness used.

Report. The report should include data sheets and curves (in λ and E values) for the test samples.

Problems. 1. Plot the curve of the data on sample 2 in the sample data sheet (Fig. 12.34):

(*a*) on a λ (mμ)—E system of ordinates.
(*b*) on a ν (f) and ν' (cm^{-1})—E system of ordinates.

(*c*) on a λ (mμ)—% transmission system of ordinates. (See Table XI for the necessary conversion values of *E*.)

(*d*) Dot in on (*a*) and (*c*) the approximate curves for a solution of half the concentration of the original sample.

2. (If Exercise 10 is omitted, the problem at the end of that exercise should be introduced here.)

Supplementary Experiment

A number of spectrophotometers are so constructed as to permit the observation of reflection as well as absorption spectra (Fig. 12.33). The reflection curves are usually broader than absorption curves, and hence one does not need to make observations closer than 10 mμ. The procedure of observation is essentially the same as in the determination of visual absorption (i.e., setting the wavelength to definite values and adjustment of the extinction to a match of the two beams). The comparison sample in the case of reflection may be a piece of undyed or colorless material of the same sort as the sample under test, or the standard white produced by a magnesium carbonate block.

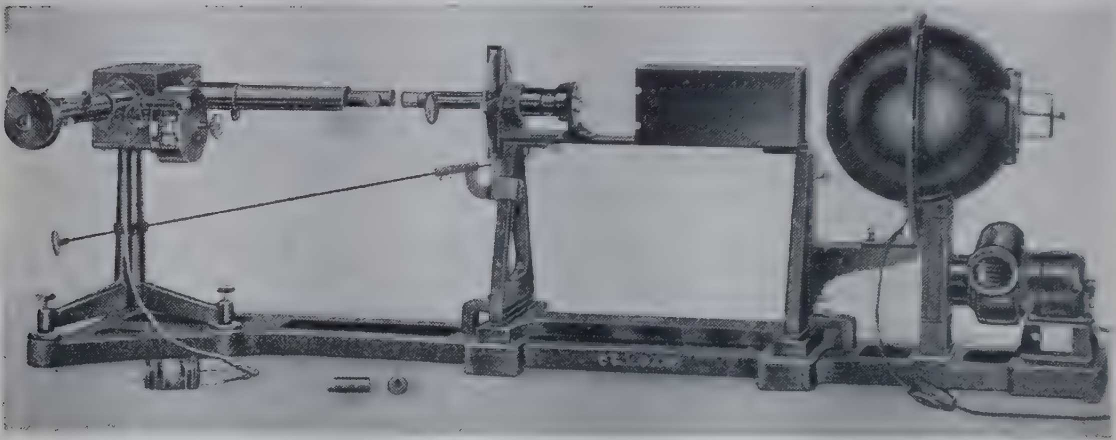


Fig. 12.33. Reflection spectrophotometer (Bausch and Lomb).

Since most reflection spectra are taken in connection with color analysis it is usual to record the data in percentage of light reflected (equivalent to percentage of light transmitted by transparent samples). It is suggested that the data obtained in this experiment be converted from extinction to percentage reflected. See Table XI for conversion values.

Problem. Two samples of colored paper (American Crayon Company Nos. 543-O and 248-BV) are suggested as samples for these determinations. The sample data sheet (Fig. 12.34) represents the observations on these papers as made with a Bausch

Fig. 12.34

SPECTROGRAPHIC LABORATORY

No. . . . .

VISUAL SPECTROPHOTOMETRIC ANALYSIS

Sample (1) *Orange 543-0* Reflection Spectra Observer. . . . .

(2) *Blue Violet 248-BV* Date. . . . .

Comparison MgO

	(1)		(2)			(1)		(2)	
	Extinction	Av.	Extinction	Av.		Extinction	Av.	Extinction	Av.
440	*0.50 0.55 0.54*	*0.53*	*0.21 0.18 0.27*	*0.22*	590	*0.00 0.00 0.01*	*0.00*	*0.68 0.71 0.70*	*0.70*
(682)					*(509)*				
450	*0.54 0.56 0.63*	*0.58*	*0.29 0.21 0.24*	*0.25*	600			*0.75 0.74 0.75*	*0.75*
(667)					*(500)*				
460	*0.64 0.61 0.69*	*0.65*	*0.32 0.28 0.26*	*0.29*	610			*0.71 0.73 0.75*	*0.73*
(652)					*(492)*				
470	*0.66 0.67 0.70*	*0.68*	*0.30 0.29 0.33*	*0.31*	620	*0.00*	*0.00*	*0.70 0.66 0.67*	*0.68*
(638)					*(484)*				
480	*0.69 0.65 0.72*	*0.69*	*0.34 0.42 0.37*	*0.38*	630			*0.59 0.65 0.63*	*0.62*
(625)					*(476)*				
490	*0.64 0.66 0.69*	*0.67*	*0.46 0.35 0.42*	*0.41*	640			*0.47 0.50 0.55*	*0.51*
(612)					*(469)*				
500	*0.68 0.62 0.65*	*0.65*	*0.52 0.45 0.43*	*0.47*	650	*0.00*	*0.00*	*0.36 0.40 0.44*	*0.40*
(600)					*(462)*				
510	*0.67 0.52 0.67*	*0.65*	*0.53 0.50 0.51*	*0.51*	660			*0.32 0.37 0.29*	*0.33*
(588)					*(455)*				
520	*0.64 0.63 0.63*	*0.63*	*0.57 0.59 0.56*	*0.57*	670			*0.32 0.26 0.22*	*0 27*
(577)					*(448)*				
530	*0.58 0.58 0.57*	*0.58*	*0.63 0.64 0.65*	*0.64*	680			*0.20 0.21 0.25*	*0.22*
(566)					*(441)*				
540	*0.47 0.50 0.48*	*0.48*	*0.67 0.67 0.68*	*0.67*	690	*0.00*	*0.00*	*0.12 0.20 0.16*	*0.16*
(556)					*(435)*				
550	*0.36 0.37 0.36*	*0.36*	*0.68 0.67 0.69*	*0.68*	700			*0.20 0.09 0.10*	*0.13*
(546)					*(429)*				
560	*0.24 0.26 0.23*	*0.24*	*0.65 0.66 0.66*	*0.66*	710				
(536)					*(423)*				
570	*0.08 0.12 0.10*	*0.10*	*0.66 0.68 0.65*	*0.66*	720				
(526)					*(417)*				
580	*0.02 0.00 0.04*	*0.02*	*0.67 0.69 0.67*	*0.68*	730				
(517)					*(411)*				

and Lomb reflection sphere attached to the spectrophotometer (Fig. 12.35). If a reflection spectrophotometer is not available it is suggested that these data be plotted and reported as observed samples.

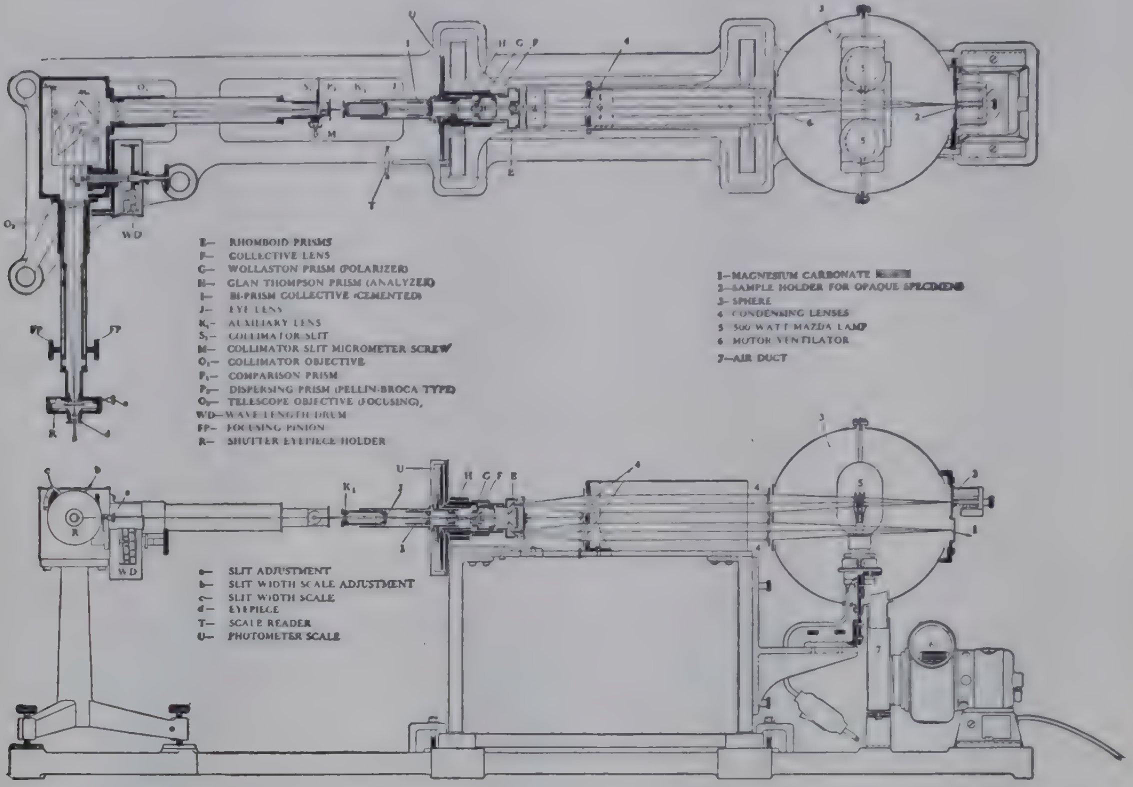


FIG. 12.35. Diagram of reflection spectrophotometer (Bausch and Lomb). (See Fig. 12.33.)

Report. The results of this supplementary experiment are to be reported on two graph sheets. On each graph sheet are to be plotted the observed extinction (E) against λ (mμ); the reflection (%) against λ (mμ); and by circled points the data obtained from the sample data sheet (Fig. 12.34).

EXERCISE 9

DETERMINATION OF ULTRAVIOLET ABSORPTION SPECTRA

Ultraviolet absorption spectra may be determined on a medium spectrograph (Bausch and Lomb, Hilger, etc.) to which has been attached a suitable photometer (Hilger sector photometer, Bausch and Lomb sector photometer, Hilger Spekker photometer, etc.) (Fig. 12.36).

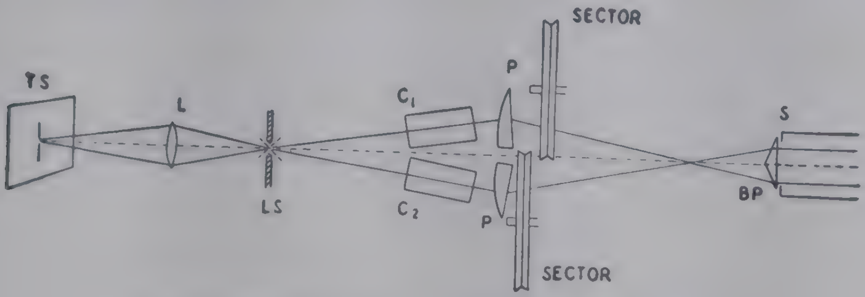


FIG. 12.36. Sector photometer (Hilger).

Light Source. Although in many laboratories a simple steel arc is use as a light source, a continuous light source has been found to be more satisfactory. Two types of continuous light sources are available, the hydrogen discharge and the underwater spark (*C131*). As in the case of the simple arc spectrum adjustment on the apparatus (Exercise 1), the optical line can be easily determined by placing an electric lamp at approximately the position of the red end of the plate holder, opening the slit to about 0.2 mm, and projecting a beam of light through to the focusing test screen.

FIG. 12.37

SPECTROGRAPHIC LABORATORY

PLATE RECORD

Serial Plate No.*................ Observer..........No.†.......

*Serial Plate-record book must be signed for each plate. *Observer number* must be indicated if *serial number* is not used on plate.

ANALYSIS FOR........

....

†Note: Use initial or other symbol to avoid confusion with serial number, e.g., W-10. *Observer number* of *serial number* must be written on plate.

Instrument............................ Date.............

	√	mm.	Sample	Time	Slit	Focus	*E*	*E*–0.3
1								
2								
3								
...	......	......	......	......	......	......	......	......
25								

Photometer. The specific directions given below are for a modified

Hilger sector photometer and medium Bausch and Lomb spectrograph. Other photometers work on the same principle with a few variations in construction. This photometer involves the separation of the light into two beams, one of which passes through the absorbing substance, while the other passes through the solvent and an adjustable rotating sector or other photometric device. By taking a series of photographs at different settings of this sector, it is possible to approximate the same effect as would be obtained on the visual machine by setting the extinction to a given value and moving across the spectrum by adjustment of the wavelength drum. At any point in the spectrum where the transmission of the absorbing material is the same as that of the rotating sector, the two beams will match. If one records these sector or photometer values, it will be possible to plot the absorption against the wavelength or frequency and thus to obtain the absorption spectrum of the absorbing substance.

Experimental Procedure. The observations are to be recorded on a plate record sheet (Fig. 12.37), and are to be made in the following manner: The first photograph taken at a setting of 0 is to be a scale; the second at 4 mm, a comparison photograph in which the cells are not placed in the apparatus and in which both sectors are open and stationary or diaphragms are set for complete transmission. This comparison photograph will indicate whether the two beams are in proper adjustment. The two cells are now placed in their proper positions, the bottom being inserted first. The cell in the beam from the fixed sector or diaphragm should be the solution of the absorbing compound, and the cell in the other beam should be the solvent. The sector or photometer diaphragm in front of the solution cell should be at 0 extinction (completely open) and the solvent sector or photometer at an extinction value of 0.1. The third photograph now should be taken at a millimeter setting of 8, and each succeeding photograph should be taken at successive settings of +4 mm each. The fourth photograph is taken as before with both sectors running, but with the extinction on the solvent sector set at 0.2. The fifth photograph would normally be taken in the same manner with the extinction set at 0.3 for the solvent (top) sector, and at 0 for the bottom sector with both sectors running.

Variation in Procedure with Sector Photometers. With certain types of two sector photometers (Hilger or Keuffel and Esser) a modification in the usual procedure is possible at this point. An examination of the percentage values equivalent to the extinction units will show that an extinction of 0.3 is equivalent to 50 per cent transmission. It is thus possible to remove the belt from the bottom sector, to leave it open and stationary, and to subtract 0.3 from the readings on the solvent (top) sector and have the same relative transmission, so that, starting with photograph 5, the solution (bottom) is set at open and remains stationary, and the top sector is set at 0.3 less than the indicated extinction, or, in this case, 0. The sixth photograph is obtained by moving the plate holder down an additional 4 mm, setting the top sector at 0.1 ($E = 0.1 + 0.3 = 0.4$), and leaving the bottom one stationary.

Experimental Procedure (*continued*). Photographs are continued at every 4 mm with increase in extinction values of 0.1 at each exposure up to an extinction setting of 1.4 (equivalent to a sector setting of 1.1 in the modified procedure). The sector values by the modified method are recorded in the column $E - 0.3$ in the data sheet, the true extinction being this value plus 0.3. The two cells are now interchanged, the solvent being placed in the bottom beam and the solution in the top beam. The top sector is left open and stationary, and successive photographs are made at extinction values on the lower sector of 1.0, 0.5, and 0.0. Both cells are now removed, both sectors set at open, and a photograph taken for comparison of the two beams (this should be at a millimeter setting of 76). The last photograph (millimeter setting of 80) should be a scale photograph.

Exposure Time. The exposure time will vary, depending upon the curve and the extinction value. The exposure time is also a function of the intensity of the light source at the slit and the sensitivity of the photographic plate. For example, the comparison photographs may be made at exposures of 5 seconds, and the extinction photographs be started at 5 seconds for the lowest extinction value and increase in time as the extinction increases so that the highest value (for 1.4 extinction) should approximate 1 minute. The following table may serve as an example:

EXTINCTION	EXPOSURE TIME (seconds)	EXTINCTION	EXPOSURE TIME (seconds)
0.0	5	0.8	16
0.1	5	0.9	20
0.2	5	1.0	25
0.3	5	1.1	31
0.4	6	1.2	40
0.5	8	1.3	50
0.6	10	1.4	64
0.7	13		

If one knows that the compound does not have an absorption band in the extreme ultraviolet, or the extinction of the extreme ultraviolet band is low, it is quite permissible to reduce the exposure times at the higher extinction settings.

The above technique, indicated for a particular type of equipment, is equally applicable to other ultraviolet spectrophotometers employin the photographic principle. In some of these, such as the Hilger Spekke photometer and the Bausch and Lomb sector photometer, there is n

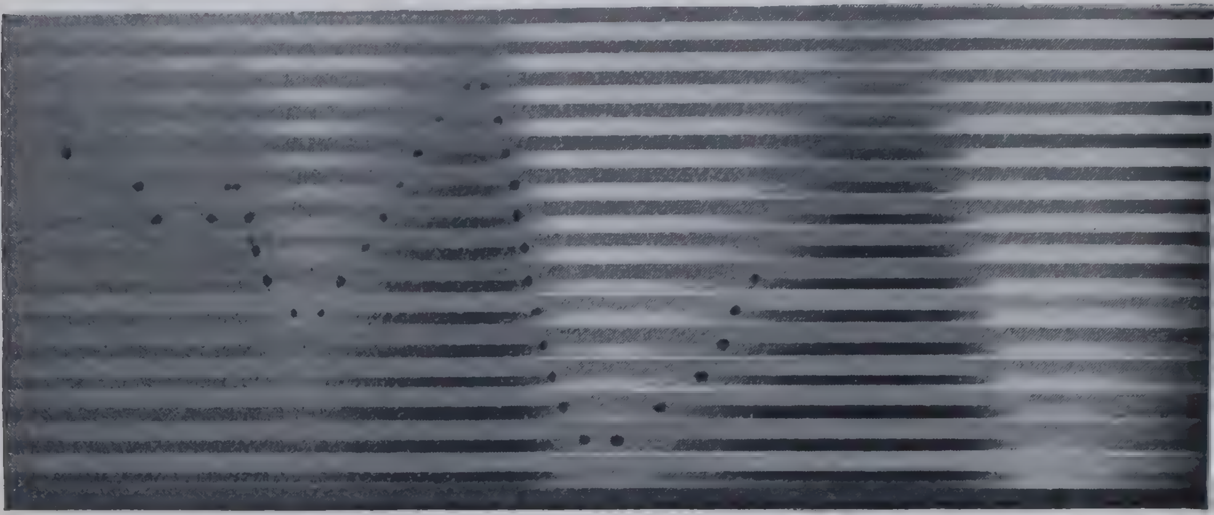


Fig. 12.38. Partial spotting of negative.

provision for the increase of light and decrease of exposure time by the use of an open beam in the solution path, or for the interchange of solution and solvent so as to correct for any instrumental error in adjustment or light path. With these photometers one should make about the same number of exposures (the actual number is determined by the limits of

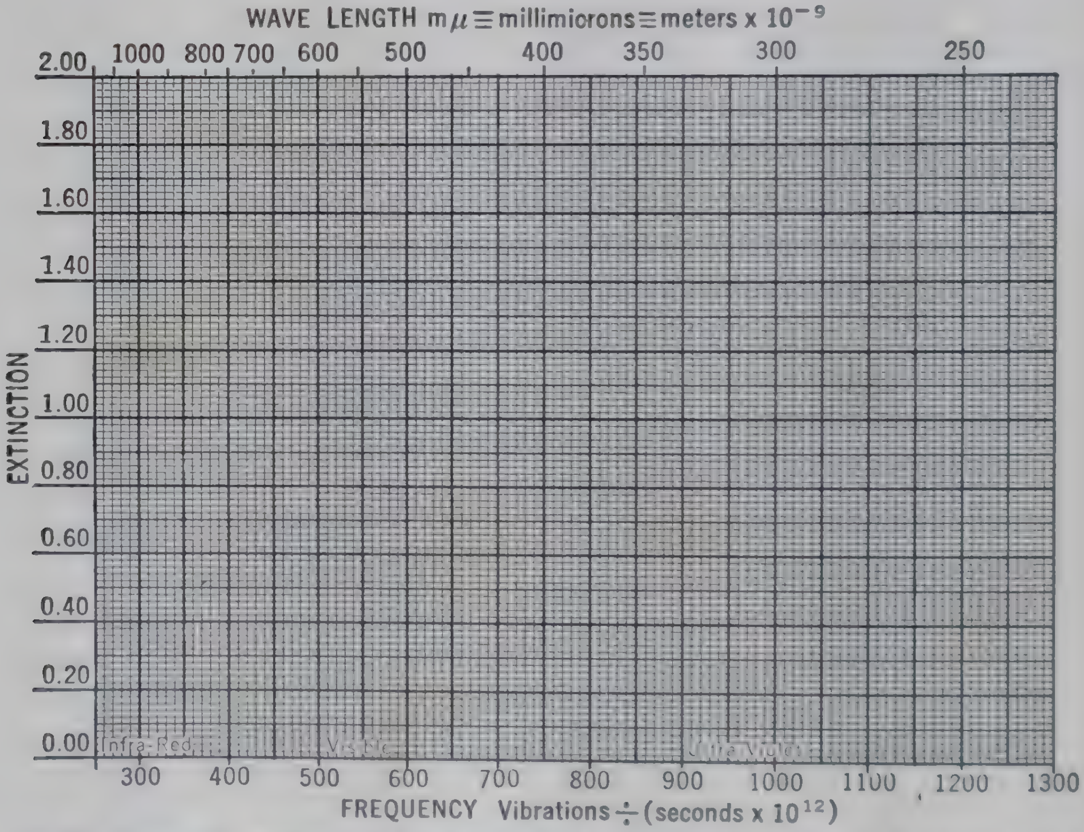


Fig. 12.39. Form for graphical recording of ultraviolet spectrophotometric data.

plate motion and size of the biprism or diaphragm at the slit); i.e., the extinction should be varied from 0.0 to 1.5 to 1.8.

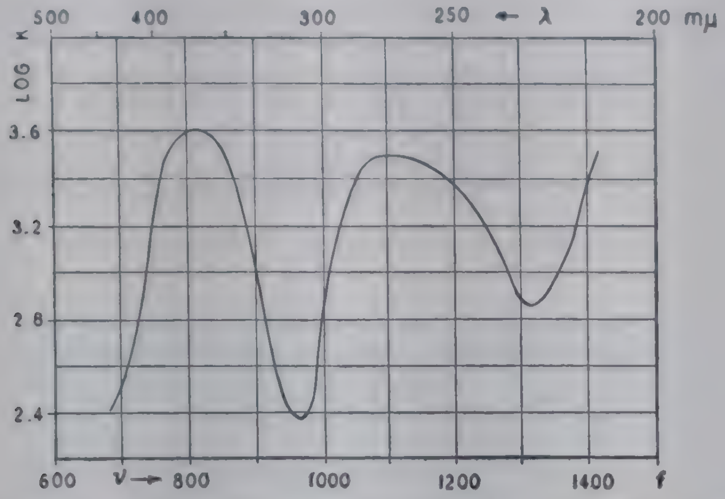


Fig. 12.40. Potassium dichromate (frequency scale—see Fig. 7.63 for wavelength scale).

Spotting and Reading of Plate—Report. The plate is developed in the usual method, and when it is dry the match points are to be spotted.

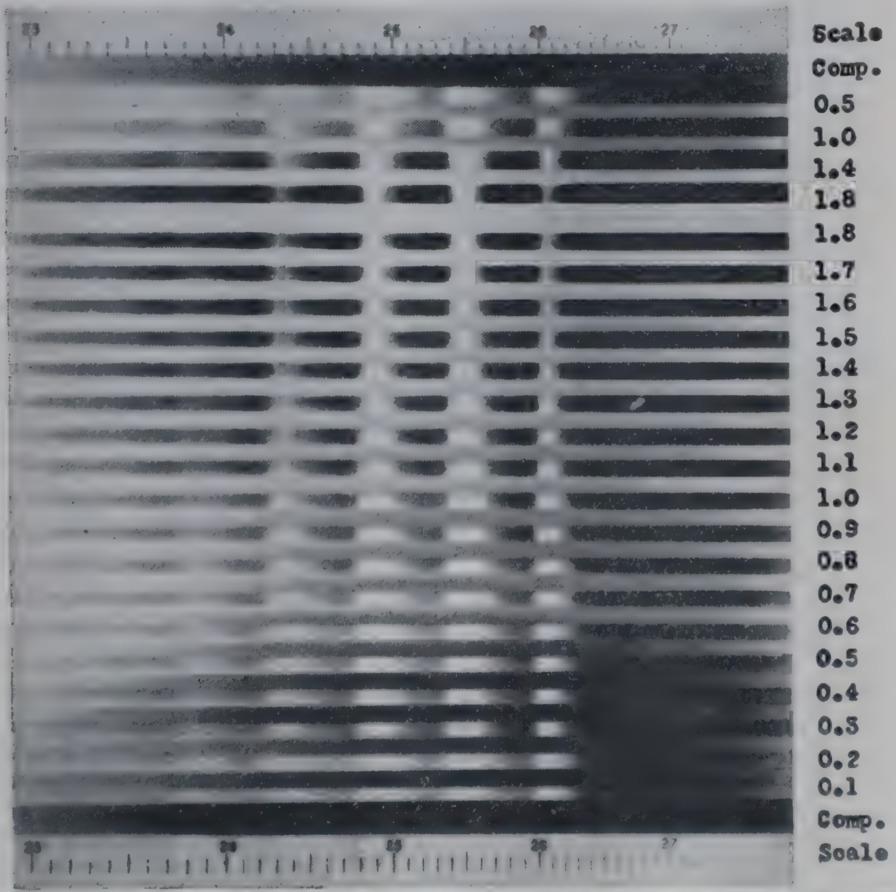


Fig. 12.41. Absorption spectrum of benzene, $c = 2.64$ cg per liter, $d = 0.4$ cm. Extinction values as indicated.

This is done on the glass side so that the spots may be removed, **and not on the film,** a dot being placed on the dividing line between the two beams whenever they have the same intensity (Fig. 12.38). If it i desirable to plot the curve in wavelength values, they may be read off directly by means of the printed scale; but, if frequency values are to b plotted, a special plate with a frequency scale (see Fig. 7.62) should b set on top of the plate, and the values read off directly in frequency units. These values are to be recorded on the data sheets and then plotted on the appropriate graph form (Fig. 12.39).

Standard Samples and Unknowns. It is suggested that a solution of

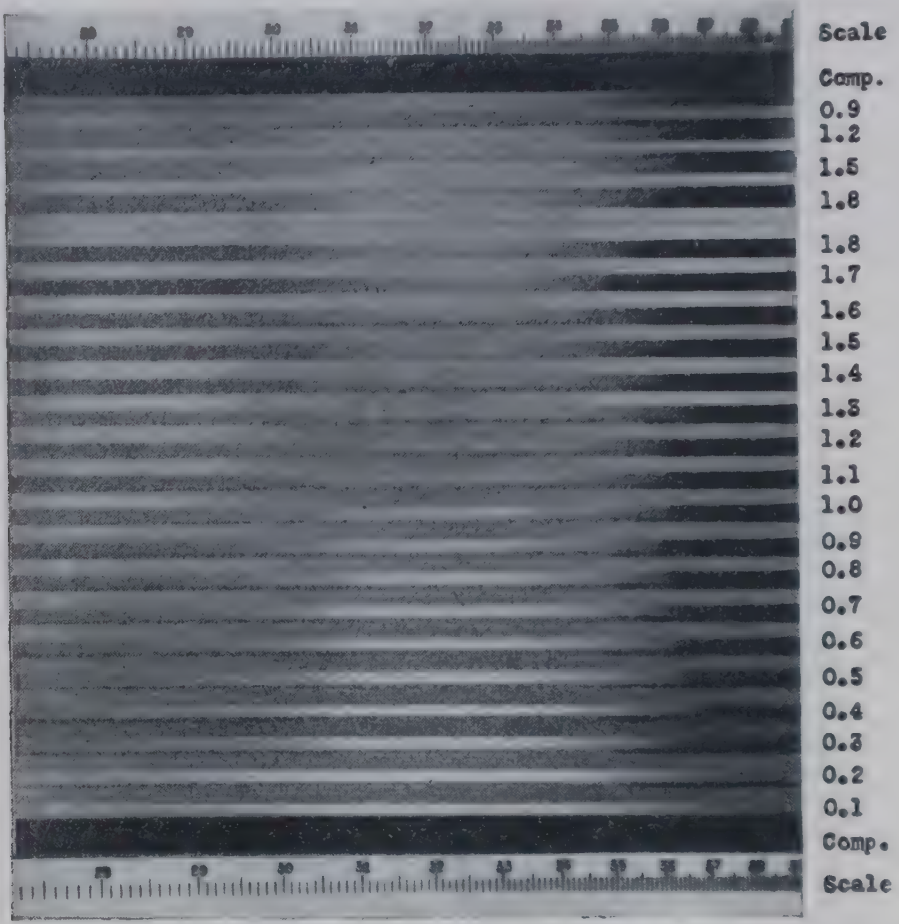


FIG. 12.42. Absorption spectrum of cod-liver oil, $c = 0.0057$ gram per 100 ml, $d = 0.4$ cm. Extinction value as indicated.

$K_2Cr_2O_7$ (*C171*) (Fig. 12.40), azobenzene (*C21*) (Fig. 7.2), benzene (Fig. 12.41), or cod-liver oil (Fig. 12.42) be used for the analytical specimen. The concentration (c) of these solutions will depend upon the thicknesses (d) of the cells which are supplied with the photometer. The glass ring cells with quartz cover plates will be found to be very convenient for this work. The cover plates can be held on by spring clip, rubber tubing, or metal frame. (See Figs. 7.39, 7.40, 7.41 and 7.42.)

Problems. 1. Figure 12.42 shows the absorption spectrum of a sample of vitamin A concentrate (cod-liver oil). Taking the extinction of the absorption band at 328 mμ as characteristic of vitamin A, and assuming that the photographs were made in the same order as the above sample, i.e., scale, comparison, 0.1, 0.2, 0.3, 0.4, 0.5 E, etc., up to the cell reversal point, determine the extinction of the maximum of the curve, and from the factor

$$\text{(at 328 m}\mu\text{)}\ E_{1\,\text{cm}}^{1\%} \times 2200 = \text{international vitamin A units}$$

calculate the vitamin A concentration of the oil from the above and the following data: concentration = 0.0057 gram per 100 ml; cell thickness = 0.4 cm.

2. Figure 12.41 shows the absorption spectrum of benzene in alcohol, concentration = 2.64 cg per liter, cell thickness = 0.4 cm. Spot the match points in this figure, and, from the extinction values given at the side and the wavelength scale at the top and bottom, record and plot the absorption spectrum.

EXERCISE 10

PHOTRONIC COLORIMETERS

Electrical and Optical Principle. In recent years a number of photroni cell photometers and colorimeters have been developed for the measur ment of the color intensity of colored liquids or glasses by transmission or papers and solids by reflection. In all these instruments the optica system as shown in Fig. 11.8 is usually employed, with certain modifi cations for reflection measurements.

The current from the photronic cell is usually coupled to a microammeter with a shunting resistance which is variable in definite steps. By means of a suitable cell, ammeter, slide resistance, and step resistance intensity variations from 1 to 10,000 can be easily measured with a accuracy of about 4 per cent.

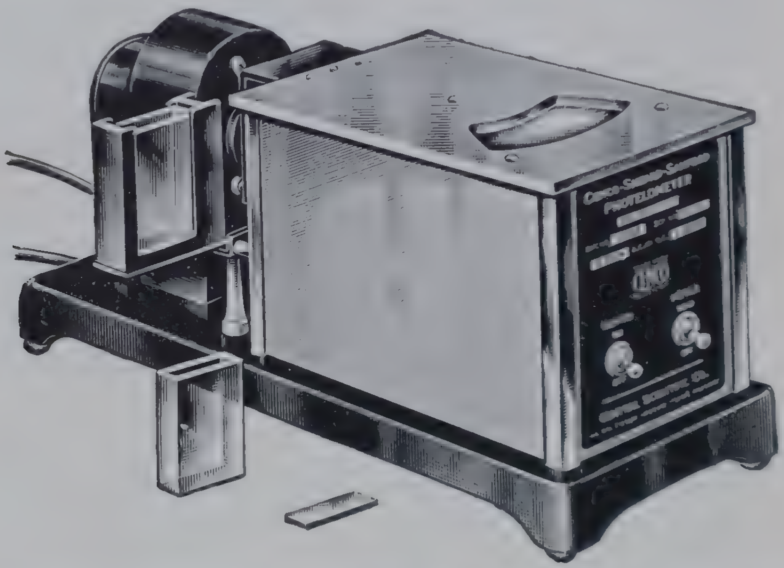


FIG. 12.43. Photronic colorimeter (Central Scientific Company). (See Fig. 11.8 for optical diagram.)

A slide resistance enables the operator to adjust the reading to a unit value such as 200, 500, etc., when it is desired to measure one substance against another to determine relative differences. A step resistance provides a means of measuring intensities quantitatively.

Some instruments have an exponential microammeter to provide a wide range with increasing accuracy at lower values so as to avoid the use of sliding or step resistances. The construction of a suitable colorimeter is not difficult since the essential parts, microammeter and photronic cells, are easily available. In the absence of a suitable manufactured instrument of this type or one built in the laboratory, satisfactory measurements can be made in this experiment, as well as laboratory determinations of color values of solutions, by means of the ordinary photronic photographic exposure meter such as produced by Weston, General Electric, or Zeiss. A suitable diaphragm such as is provided with the

General Electric meter to transmit $\frac{1}{10}$ of the light permits a wide range of accurately measured intensities. In the absence of a diaphragm one can employ the simple optical bench relations of variation of intensity with the square of the distance from the source as a means of variation of incident intensity, rather than keep the source and cell at a constant distance and vary the intensity by a screen.

Experimental Procedure. The cell should be placed at a fixed distance from the light source so that with the $\frac{1}{10}$ filter in position the needle should indicate a nearly maximum value. This value should be recorded and then colored cellulose films or glass filters should be interposed between the light and the photronic cell (in the General Electric exposure meter immediately in front of the $\frac{1}{10}$ filter). If the value on the meter drops down to less than $\frac{1}{10}$ of the original reading or the capacity of the meter, then the $\frac{1}{10}$ filter should be removed. (Be sure that the direct light does not strike the photronic cell so as to cause the needle to swing beyond the indicated capacity of the instrument.) Readings are to be made on all the colored samples which are supplied. It is suggested that small pieces slightly larger than the opening of the colorimeter be attached or mounted in cardboard squares with an aperture of the proper size or between lantern slide glasses so as to permit their repeated use as filters and to provide convenient mounting in front of the photronic cell.

Application of Data. The object of this experiment is to demonstrate how a simple photronic colorimeter can be used as a spectrophotometer in the measurement of color shades and intensities. The principles involved in this exercise require the subdivision of the visual spectrum into segments and the measurement of the color intensity in each of these segments. This is essentially what is done in ordinary spectrophotometry, Exercise 8, except that in that exercise the spectral segments were determined by the ocular and entrance spectrometer slits and were of the order of 1 or 2 $m\mu$. In this exercise we will divide the visual spectrum into five or six color sections (quite satisfactory results in the description of color have been obtained by the division of the spectrum into only three primary colors [Chapter XI]).

Standard colored glasses (Fig. 11.10), filters, or colored Cellophane may be used as the dividers of the visual spectrum (Fig. 12.32). The object of this experiment is to demonstrate certain spectrophotometric principles of color measurement, and workers are cautioned against the use of uncalibrated filters for very exact colorimetric analysis. Even though every effort has been made to obtain uniform filter samples it is, of course, difficult in the production of large quantities of relatively in-expensive colored films to maintain an accurate control on the dye strength or thickness, and sometimes the dyes themselves may fade on continued exposure to light. In the application of these filters it will be necessary to know the spectral transmission curves which are given in Fig. 12.44 together with the relative visibility curve of the eye.

An examination of the extinction curves of the Cellophane filters will indicate that double-thickness pieces of the yellow, orange, and red and single-thickness pieces of the green and blue will provide a better subdivision of the spectrum than single-thickness filters for all colors. In addition it will be noted that both the blue and green filters have a transmission region in the far red portion of the spectrum. The use of a combination blue and red filter or a green and red filter will provide an additional spectral segment which should be included in the series of observations made with the Cellophane filters, and values obtained with both the green and the blue filters should be corrected by the subtraction of the extreme red transmission value obtained by this combination blue (or green) and red filter. The following dominant wavelength values are suggested for the Cellophane filters:

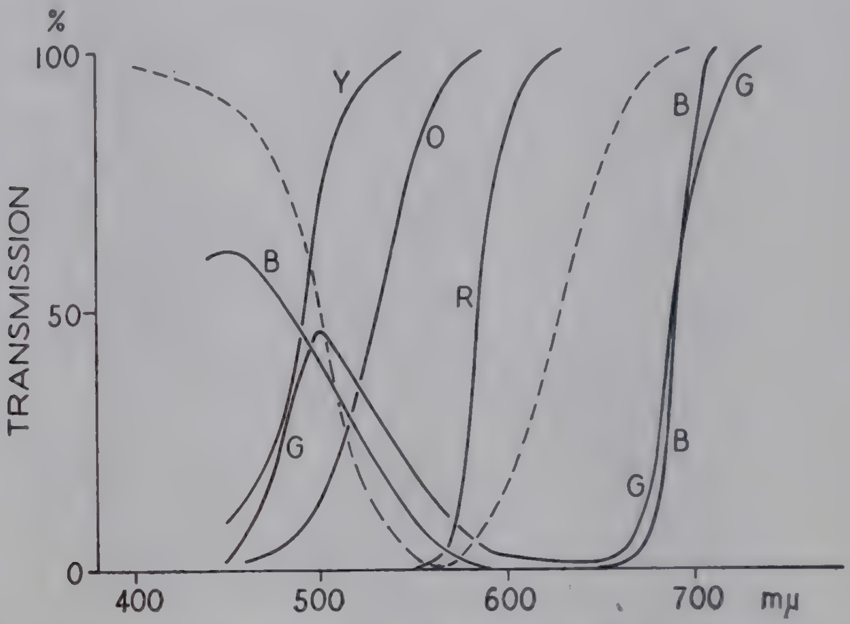


FIG. 12.44. Transmission curves of colored Cellophane samples. (See Fig. 12.32 for extinction curves.) (Dotted curve indicates relative visibility.)

Blue (1×)	470 mμ
Green (1×)	510
Yellow (2×)	560
Orange (2×)	600
Red (2×)	660
Red (2×) + Blue (1×)	690

In the use of these values it should be remembered that the corrected orange value of 600 mμ represents the difference in transmission between the orange and the red filters, or the spectral segment which is transmitted by the orange but not by the red filter. A similar correction has been applied in the assignment of the corrected yellow value, in that this represents the spectral segment which is transmitted by the yellow but not by the orange filter.

The indicated dominant wavelength values for the green and blue filters require a similar correction in the form of subtraction of the red + green (or blue) transmission from the green (or blue) transmission. The spectral segment obtained by the use of the red + blue filter (690 mμ) is so near the limit of visual perception that it may be neglected in the subdivision of the spectrum for visual color analysis. The values obtained for this far red segment should, however, be applied as correction values to the blue and green filter observations.

The data obtained by the direct measurement of the transmission intensity of the set of five filters (red, orange, yellow, green, and blue, but not purple) should be compared with the transmission curves given in Fig. 12.44. It may be assumed that these filters divide the visual spectrum into five sections of approximately equal range with dominant wavelengths characteristic of each color. If the total intensity of the white light is observed as 500 foot-candles, and it is assumed that the energy distribution of the white light is about equal over the visible wavelength range, then one may assign to each of the component colors $\frac{1}{5}$ of this value, or 100 foot-candles, to each region. From an examination of the transmission curves of the red, orange, and yellow filters (Fig. 12.44) it can be seen that the yellow filter transmits all the red and orange light as well as the yellow, and the orange filter transmits the red as well as the orange, hence the spectral yellow value (Y_0) will be equivalent to the observed filter yellow value (Y_1) less the observed filter orange value (O_1), i.e., $Y_0 = Y_1 - O_1$; and in like manner $O_0 = O_1 - R_1$. If the observed yellow, orange, and red values for the filters measured against a white light are $Y_1 = 310$, $O_1 = 215$, and $R_1 = 105$, then the spectral values for these three colors will be $Y_0 = 310 - 215 = 95$; $O_0 = 215 - 105 = 110$; and $R_0 = 105$.

The intensity factor and dominant wavelength may be determined for each color by the area and the center of the surface bounded by the absorption curve of the filter and the relative sensitivity of the eye curve (Fig. 12.44). In the case of compound colors such as yellow, which in the filter includes both orange and red, the dominant wavelength of the spectral yellow is determined by the area bounded by the absorption curve of the yellow filter, the absorption curve of the orange filter (whose energy is to be subtracted from the yellow value), and the visibility curve (Fig. 11.1).

For the filters shown in Fig. 11.10 the following assignments of dominant wavelength may be used: red = 660 mμ, orange = 610 mμ, yellow = 575 mμ, green = 530 mμ, blue = 470 mμ. The student should compare the transmission curves of his filters (Fig. 12.32) with the above assignments and filter curves and make his own division of the visible spectrum. The original assumption that each filter could be considered as transmitting the same amount of spectral energy was based on an assumed division of the spectrum into five equal energy regions and an assumed 100 per cent transmission of the energy in this region by the filter. Certain filters, especially the green, have an appreciable absorption in the region of maximum transmission or dominant wavelength. It will therefore be necessary to multiply all values observed with this filter by a constant so as to bring readings taken with this type of filter to the same basis as the other filters.

It may also happen that the area of transmission of (or energy transmitted by) one of the filters may be greater than the assigned $\frac{1}{5}$ of the spectral region, and hence it will be necessary to correct this filter value by multiplying by a factor of less than 1 to bring its readings to the same basis as the other filters. For example, if the green filter gives an energy transmission of 45 and the blue filter a value of 135 foot-candles, where the original white light reading is 500 and the division into equal energy would give 100 foot-candles to each spectral region, the correction factor for the green will be 100/45 or 2.22, and the correction factor for the blue will be 100/135 or 0.74. It is thus possible to measure a white-light source with photometer and determine the total energy, and by repeating the measurements with the set of filters, to assign relative intensities to each of these filter spectral regions. These values should all be equal and represent 100 per cent transmission for each of these regions.

Measurement of Unknowns. If a colored glass, solution, or one of these filters (it is suggested that the green or purple filter be used) is to be measured, it should be placed in front of the photronic cell and its total transmission measured. It should then be placed with each of the five filters in turn in front of the cell and the spectral transmission with the filter determined. The corrected values for the spectral regions, when added together, should be approximately the same as the original total transmission of the filter (based on the assumption that the five-way division by the filters is in approximately equal energy distribution).

Dividing the corrected values for the white light for each filter into the corrected values for the interposed sample for the corresponding filter one can obtain the percentage of light transmitted in each spectral region. These values should be plotted and the transmission curve indicated from the five points. The observations on the above two samples (purple and green filters) should be repeated for a three-thickness piece of the sample.

Report. The final report should include a data sheet indicating:

(*a*) Total energy or light intensity of source (this may be an extrapolated value by use of a 1/10 or other reducing filter if the original source is too bright for direct measurement).

(*b*) A tabular indication of the values for each filter, dominant wavelength, correction factor, corrected values, and total energy by summation of filter segments.

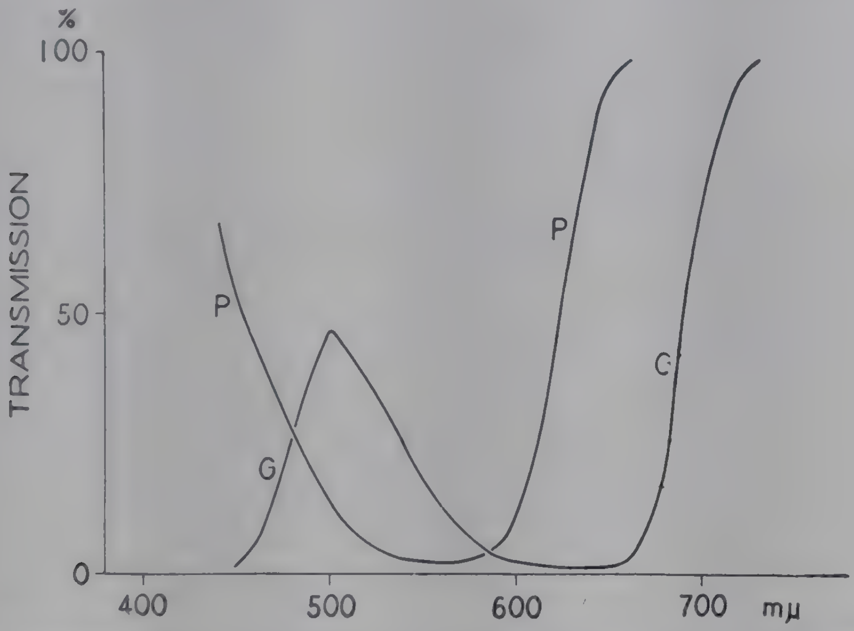


FIG. 12.45. Transmission curves of colored Cellophane samples. (See Fig. 12.32 for extinction curves.)

(*c*) A tabular indication of the values for each unknown or test sample for each filter, the corrected values, percentage transmission, total energy by summation, and direct total energy (test sample without filters).

(*d*) Graphical representation of the transmission spectra of the test samples.

Although the experiment which has been described deals with the transmission spectra of samples, it should be kept in mind that similar instruments are available for the determination of reflection spectra. If the photronic cell instrument, such as a photronic exposure meter, is not graduated in foot-candles or other direct measure of luminosity energy, it may be necessary to calibrate the scale by setting the instrument at definite distances from a test lamp and applying the principle of variation of energy with the square of the distance in the calibration of the scale. The calibration need not be in foot-candles, since the final values recorded and plotted are percentage values based on the ratio of two readings of the instrument.

Problem. From the data given in Figs. 12.32 and 12.44 or observed data in this experiment prepare curves (extinction and percentage transmission) showing the effect of combining the following filters: (*a*) purple and red; (*b*) green and yellow; (*c*) yellow and red; (*d*) blue and green; (*e*) blue, green, and yellow; (*f*) double thickness of orange.

From an examination of these curves and the observed data, suggest combinations to provide additional or better segmentation of the visible spectrum by these filters. *Note:* It should be remembered, in the addition of absorption effects, that extinction curves can be directly added together but that percentage transmission curves cannot be directly added to obtain the compound curve (see Table XI for the relation between extinction and percentage transmission).

EXERCISE 11

QUALITATIVE ULTRAVIOLET ABSORBPTION SPECTRA DETERMINATION

In its original form this experiment was intended to be performed with an ultraviolet hand spectroscope (Beck) (Figs. 12.46*a* and 12.46*b*) having an iron arc as the ultraviolet source. The spectrum as observed through the eyepiece appears as one of the strips in the following photographs (Fig. 12.47). The illuminated scale is a part of the optical system of the spectroscope. The ultraviolet hand spectroscope has a fluorescent screen upon which the spectrum and the scale are projected and upon which the eyepiece is focused. It operates, in principle, much the same as a visual hand spectroscope, and, in laboratories in which an ultraviolet hand spectroscope is not available, the experiment will have to be confined to visually colored plastics, glasses, and solutions.

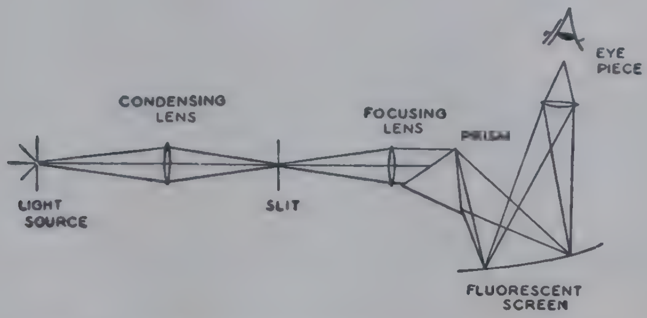


Fig. 12.46*a*. Hand spectroscope for ultraviolet (diagram).

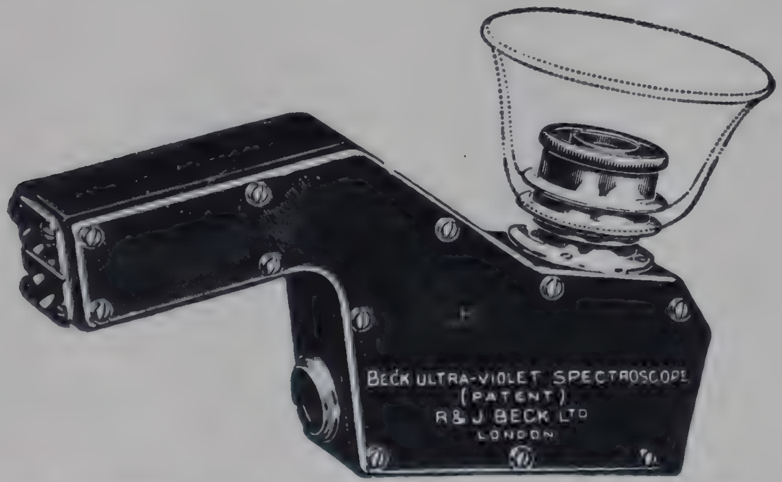


Fig. 12.46*b*. Hand spectroscope for ultraviolet (Beck).

In order to illustrate the ultraviolet absorption of some common materials the photographs in Fig. 12.47 are given. It is suggested that an estimate be made of the ultraviolet transmission of these samples as well as the samples which are provided for test. For ultraviolet measurement the following samples are suggested: various grades of plate and window glass, Vita glass, Corex, Uviol, Pyrex, microscope slides, Cellophane, Pliofilm, cellulose acetate, Celluloid, Vinylite, and Bakelite (for thin films it may be necessary to use several thicknesses).

Caution: Avoid looking directly at any ultraviolet light source.

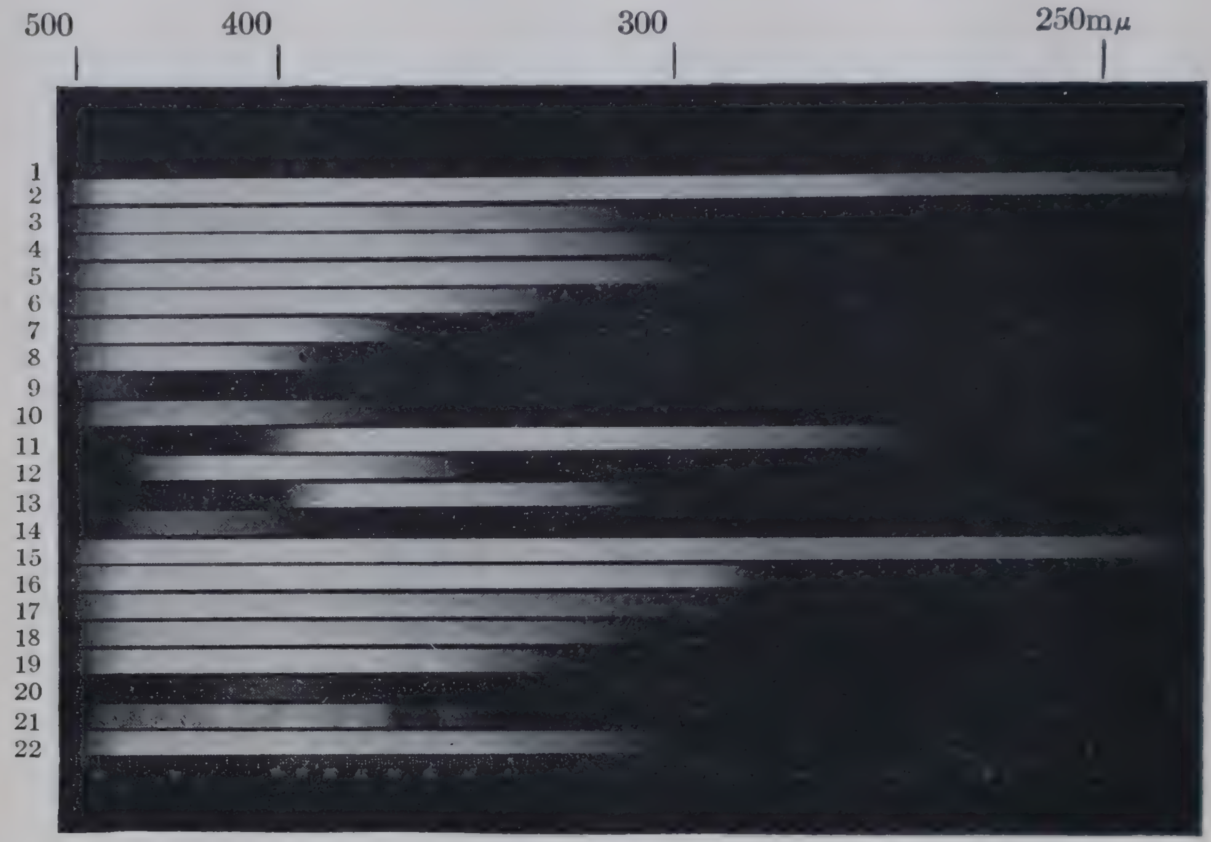


FIG. 12.47. Spectrograms of transmission samples (continuous source from underwater spark). (See Table 12.7 for identification code.)

The data should be reported as follows (this partially completed data sheet provides the necessary information for the analysis of the observations in Fig. 12.47):

TABLE 12.7

ULTRAVIOLET TRANSMISSION OF MISCELLANEOUS SAMPLES

Plate No. (*See Fig. 12.45*)
Observer....................

No.	Check	Sample	Thickness	Range of Transmission
1	√	*Scale*		
2	√	*Blank (quartz)*		
3	√	*Luster glass*	*2.3 mm*	*Visual to 2950*†
4	√	*Microscope slide*	*1.3 mm*	....
5	√	*Pyrex*	*2.6 mm*	....
6	√	*Plate glass*	*6.0 mm*	....
7	√	*Greenish nultra*	*2.5 mm*	....
8	√	*Noviol*	*3.6 mm*	....
9	√	*Sextant green*	*3.5 mm*	....
10	√	*Dark shade Alko*	*2.6 mm*	....
11	√	*Red purple Corex A*	*5.5 mm*	....

TABLE 12.7 (*Cont.*)

12	✓	*Blue (No. 14)*	*2.2 mm*	....
13	✓	*Blue (312-UC2)*	*1.9 mm*	....
14	✓	*Blue (493-BG6)*	*2.5 mm*	....
15	✓	*Cellophane (1X)**	*0.02 mm*	....
16	✓	*Cellulose acetate (1X)*	*0.02 mm*	....
17	✓	*Pliofilm (1X)*	*0.02 mm*	....
18	✓	*Celluloid*	*0.2 mm*	....
19	✓	*Methylmethacrylate*	*72.3 mm*	....
20	✓	*Red Cellophane (1X)*	*0.02 mm*	....
21	✓	*Neodymium glass*	*10.1 mm*	....
22	✓	*Zeiss GO filter*	*1.5 mm*	....
23	✓	*Scale*		....

* Single thickness=1*X*.

† Method of reporting observations.

EXERCISE 12

QUALITATIVE AND SEMIQUANTITATIVE SPECTROPHOTOMETRY PHOTOGRAPHIC PLATE SPECTRAL CALIBRATION

Apparatus. The apparatus for use in this experiment can be constructed from easily available parts (Fig. 12.48).

The light source (*LS*) may be a T-20 type prefocus-base projection bulb (110-volt, 200-watt) or a single-filament lamp of the street-lighting series type (10 volts, 6 amperes) (which can be run from a Jefferson toy or miniature electric train transformer). A more suitable though more expensive source is the single-wire galvanometer lamp. The filament is focused (L_1) as a line source on the density wedge (*W*) or step slit (*S*), adjacent to which is the cell (*C*) which can be used for spectral measurement of solutions; the cell can be replaced by filters or glasses if one wishes to measure the transmission of solid samples.

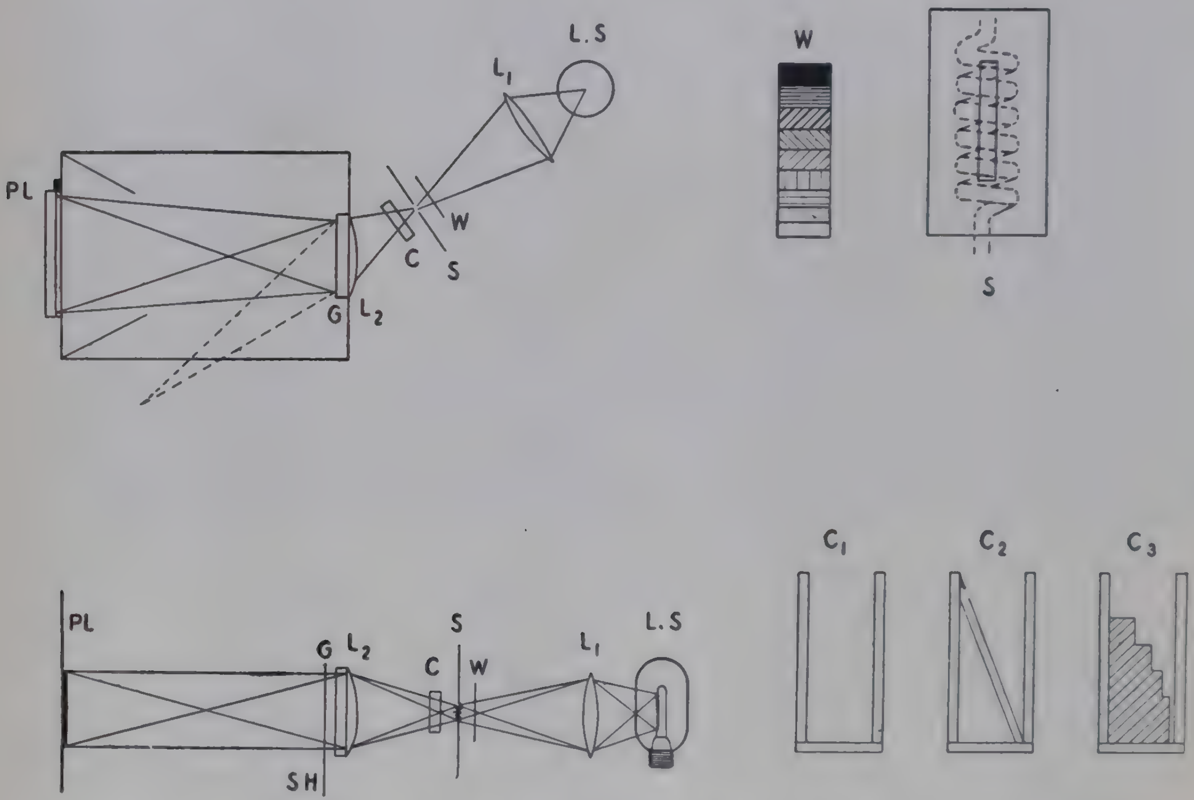


FIG. 12.48. Wedge grating spectrograph.

The grating and second lens are indicated by *G* and L_2 in the above diagram. The grating is a transparent replica grating such as is produced by casting a collodion image of a ruled grating and mounting it on glass. The second lens is placed so as to bring line spectra, produced by the substitution of a neon tube for the light source, into focus at the plate holder (*PL*). The plate holder has a permanently mounted glass plate immediately in front of it which is transparent except for a photograph of coordinate rulings and a scale which is printed on the bottom and projects onto the photographed spectrogram as a calibration background

(Fig. 12.49). It may be necessary to dye a portion of this screen plate a light yellow to absorb second-order images from the grating in the red end of the spectrum.

Experimental Procedure and Reports. The following experiments are suggested:

(*a*) Determine the spectral sensitivity of a film or plate by exposure with the density wedge. The print of the wedge spectrogram should be mounted and properly labeled to indicate the type of plate and character of spectral sensitivity. If available, additional films might be tried, keeping the exposure time uniform. The plate holder can be constructed so as to permit the use of motion-picture (35-mm) film, which is easily available in a wide variety of types, including infrared-sensitive.

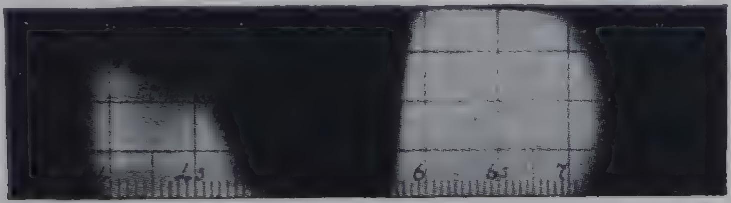


Fig. 12.49. Wedge spectrogram of Rose Bengal 5B 1/400 (Mees [*B56*]).

(*b*) Determine the spectral transmission of some colored films, using a panchromatic film for photographic observation. The report should include prints of the spectrograms mounted above approximate extinction curve diagrams reduced to the same dispersion. (These curves can be obtained from the extinction data given on these films in Fig. 12.44.)

(*c*) Determine the spectral transmission of a solution of potassium permanganate or crystal violet, reporting as above and comparing the spectrogram with the data on the same solution obtained in Exercise 8.

DEMONSTRATION OF ABSORPTION SPECTRA AND COLOR FORMATION

The method described below has been used with considerable success in the lecture demonstration of absorption spectra and color formation. It also forms the basis for a colorimeter by means of which one can produce a color match or color analysis of the most complicated type. In its simpler form this colorimeter can be used with three fixed absorbing bands as a trichromatic colorimeter, or with one or two movable bands it can simulate with accuracy practically all the simple absorbing effects which produce visible color.

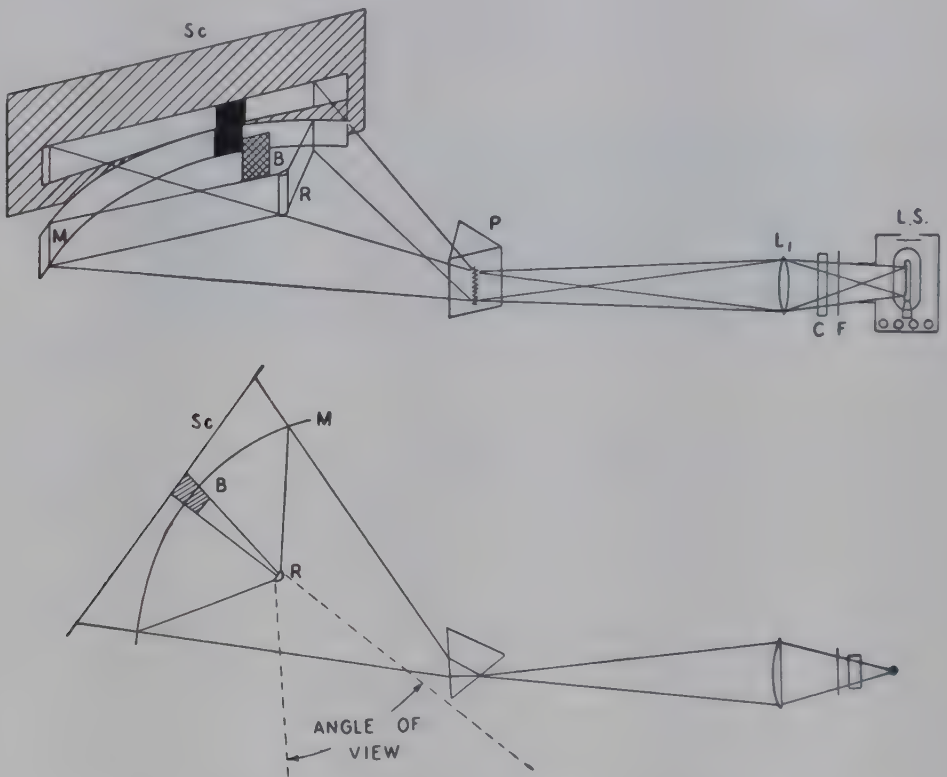


FIG. 12.50. Demonstration of absorption spectra.

The light source (*LS*) recommended for this experiment is a T-20, 500-watt projection bulb. A straight single-filament bulb taking 6 volts, 10 amperes, might be better, but such a current supply is usually not so conveniently obtained as the 100-volt current. The bulb should be placed in a protected ventilated housing so that the filament is viewed from the side as a single line. This is focused by a lens (L_1) so that the point of focus of the image will be at the prism (P). This prism can be a solid glass 60° type, or a hollow glass prism made by cementing glass plates together on a flat plate, the edges of the plates being beveled so as to form a smooth cemented joint with the water-glass cement. A hollow glass prism of this type with a ground-glass stopper can be obtained from the usual laboratory supply houses. The prism should be filled with carbon disulfide, which has a high refractive index and will produce a spectrum with a reasonably high dispersion.

The spectrum, since it is produced from a nearly parallel beam of light owing to a short-focus lens placed close to the light source, may be considered as originating as approximately a line source at the prism and will be essentially in focus at any point at which one might desire to put the viewing screen (*Sc*). With the light source placed about 10 feet from the prism and the card at about an equal distance on the other side of the prism, a spectrum about 4 feet in length and about 8 inches high is produced in sufficient brilliance to be easily viewed in a large lecture room. Immediately in front of the viewing card is placed a cylindrical mirror (*M*). For modern plate-glass windows a technique of manufacture has been developed for producing curved plate glass with a radius of curvature of 10 to 15 feet, and in the installation of such pieces it is usually necessary to cut off narrow strips. A strip of such a plate-glass piece, about 3 or 4 feet long and 4 inches wide, can be silvered by rocking in a silvering tray, much as one would develop a photographic film; it then forms an excellent cylindrical mirror for this demonstration. This cylindrical mirror should be mounted in such a manner that it collects about half the height of the spectrum on the viewing screen and allows the remainder to pass over the top of it and be visible to the audience. The collected image from the cylindrical mirror will be focused at the point

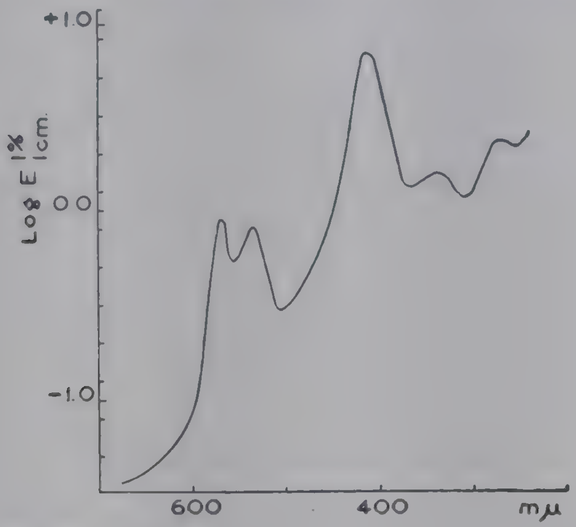


FIG. 12.51*a*. Absorption spectrum of hemoglobin.

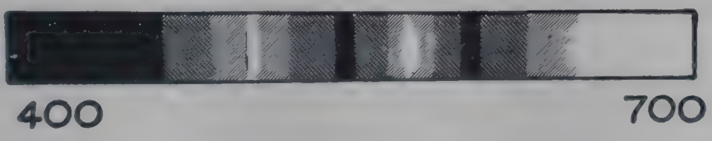


FIG. 12.51*b*. Filter strip to produce a blood-red color.

(I) in the form of a line of light which represents a recombination of the spectrum into a single color. If a focusing screen (R) is placed at this point it will be possible to see this effect, provided that the focusing screen does not obstruct the spectrum on the mirror and card. Such a screen can be produced by grinding a ⅛-inch-diameter, 5-inch-length piece of solid glass rod to a half-round cross section and focusing the light on the back or ground-glass flat face. The placing of this rod at the focal point involves a rather critical adjustment but is not difficult. The cylindrical smooth side of the rod will give a brilliant image of the ground-glass back face over a considerable angle of view.

The placing of glass filters (F) or colored solutions in cells at the point C will cause the absorption spectrum to appear on the test card with a dark band where the light is absorbed, and the color of the light transmitted by the glass or solution will appear on the focus rod (R). That the color at R is the same as the transmitted color of the glass can be easily demonstrated by placing a card at P so as to show this color. A number of black cards (B) about 10 inches in height and of varying width should be available and mounted on slotted wooden blocks so as to stand on the table. These strips, placed immediately in front of the cylindrical mirror, are equivalent in effect to an absorption band. The portion of the spectrum which is cut out by the card can be seen in the test screen, while the color produced by the elimination of that part of the spectrum by absorption is seen on the focus rod (R). The use of several cards or a glass plate with a shaded blackening with a dark streak in the center and gradual reduction in intensity towards the edge will produce a wide variety of effects. It is possible to prepare Celluloid strips the length of the spectrum and blackened in certain parts to produce gradual or total absorption and simulate such colors as blood red (Fig. 12.51) with considerable success.

CHAPTER XIII

THEORY AND PRACTICE OF PHOTOGRAPHY (*B62, A23*)

Image Formation—Emulsions

The production of a photographic image on a negative or paper is dependent on the formation of a latent silver halide image by a photochemical action; the reduction of the latent silver halide image by a suitable developer to the metallic silver image; and the removal, by a suitable solvent or fixing agent, of the unaffected silver halide. The silver halide particles which are suspended in a gelatin emulsion are photosensitive. The particles which have been affected by light form a latent image and are sensitive to the action of the developer whereas those particles which have not been activated by light are insensitive to the developing agent.

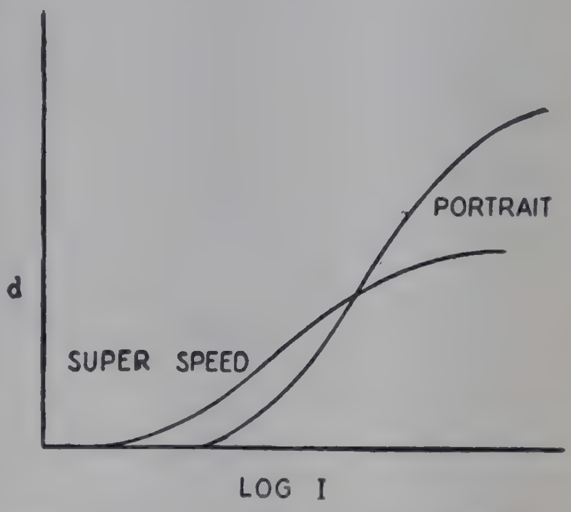


Fig. 13.1. *d*/log *I* curves for different emulsion types.

The size of the silver halide particles, and the nature of additional components in the emulsion, such as photosensitizing dyes or thiourea, determine the density of the image which will be produced by a given light intensity under standard conditions of development. In Fig. 13.1 are shown the density against logarithm of intensity ($d/\log I$) curves for two emulsion types. These curves will, of course, vary with different colors of light and developing conditions.

Since density is in itself a logarithmic value, being the logarithm of the ratio of the intensity of the incident to that of the transmitted light, the relation $d/\log I$ or $d/\log E$ should be linear over that region in which the density varies directly with the intensity or time of exposure.

Figure 13.2 shows the effect of increased time of development on the density of the image. A similar effect is shown in the change of temperature on the density of the image. As can be seen in these curves and in Fig. 13.3 there is a certain intensity or time period over which there is an increasing rise of d with log I or log E. This is followed by a region in which there is a constant rise of density, and then this is followed by a region of decreasing rate of density increase. Eventually the rate of decrease results in a maximum density which is followed by lower densities with a complete destruction of the latent image or reversal of the image.

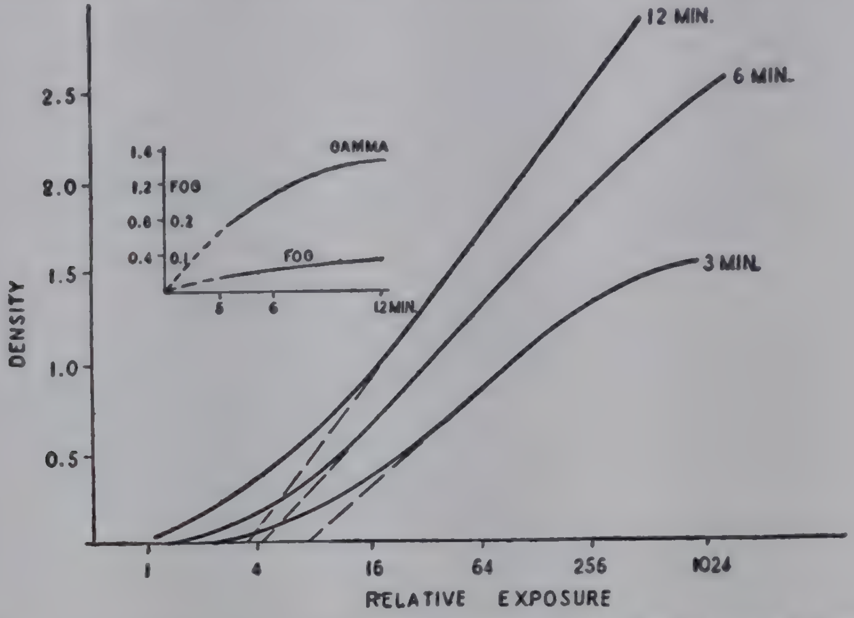


FIG. 13.2*a*. Increase in gamma (slope of straight portion of $d/\log I$ curve) with increased development time. High-speed emulsion.

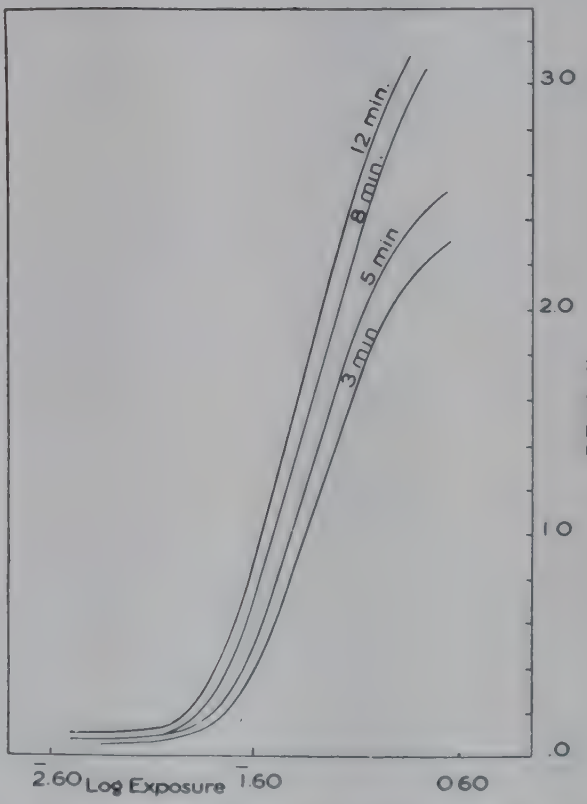


FIG. 13.2*b*. Change in gamma of spectrum analysis film (Eastman) with increase of developing time.

The most satisfactory portion of the density curve, and the one within which the exposure should be made, is the straight-line portion of the $d/\log I$ curve. If one extends this straight-line portion of the $d/\log I$ (or $\log E$) so that it meets the ordinate axis of zero density, the intensity for constant time (or exposure time for constant intensity), which is indicated, is known as the inertia of the emulsion. In order to express conveniently the rate of increase of density with the logarithm of the exposure, the term gamma (γ) is employed. By definition, gamma is the tangent of the angle produced by extension of the straight-line portion of the sensitivity curve when it meets the axis of zero density. From Fig. 13.2 and other data it can be seen that the time of development, or temperature, directly influences the size of the gamma value for a given emulsion. Short exposure and long development will result in a high gamma value; low gamma, or low contrast, values are produced by long exposure and short development.

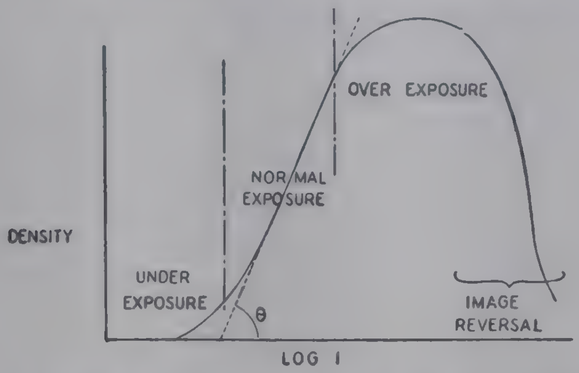


Fig. 13.3. Extended $d/\log I$ curve indicating normal exposure range, inertia (i), gamma (γ) (tan θ or slope of normal exposure), and image reversal caused by overexposure with a destruction of the latent image.

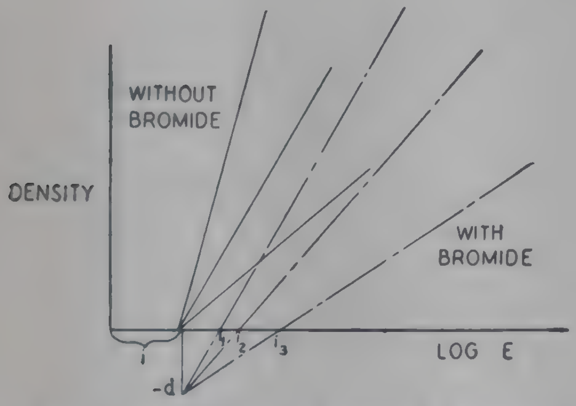


Fig. 13.4. Effect of added bromide on chloride emulsions. Note increase of inertia without loss of gamma.

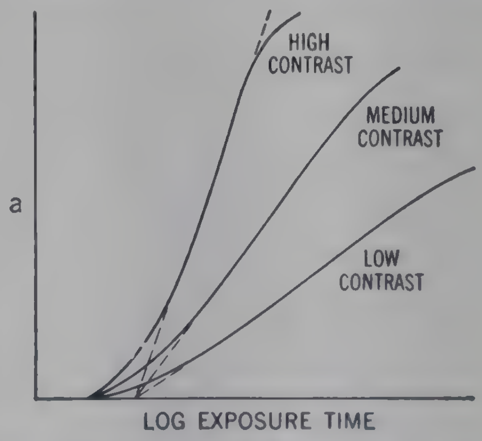


Fig. 13.5. $d/\log E$ curves for low medium, and high contrast paper emulsions.

In order to repress "fog" in the developing process, it is customary to add a small amount of potassium bromide. In the absence of bromide in the developer, the inertia of the emulsion is constant for various times, but with the addition of bromides there is a depression of the inertia point to negative density values, which results, as indicated in Fig. 13.4, in an apparent increase in the inertia value, without a corresponding decrease in the gamma or contrast value. This means that weak exposures will produce little or no effect but exposures of normal intensity will produce nearly normal images.

Emulsions designed to give the greatest possible contrast, such as the process plate, have a very limited range (about 1 to 4), whereas soft emulsions such as a portrait panchromatic may have a range of 1 to 250. The greater range indicates a greater possible variation in exposure time or light intensity which can be observed in different densities on the photographic plate. This latitude is generally much greater in film and plate emulsions than in paper emulsions (Fig. 13.5).

DEVIATION FROM THE NORMAL PHOTOGRAPHIC RESPONSE

The use of photographic emulsions in spectroscopic analysis requires that consideration be given to some factors which may influence the accuracy of the analytical results. The reciprocity law (*D12a*) would require that the photochemical effect produced be proportionate to the energy applied. It has been shown that there is a *failure of the reciprocity law*, i.e., very long exposures of low intensity will not give a density equal to short exposures of high intensity although the product of intensity by time may be constant in the two cases. In Fig. 13.6 an example of the failure of the reciprocity law is shown. As can be seen from

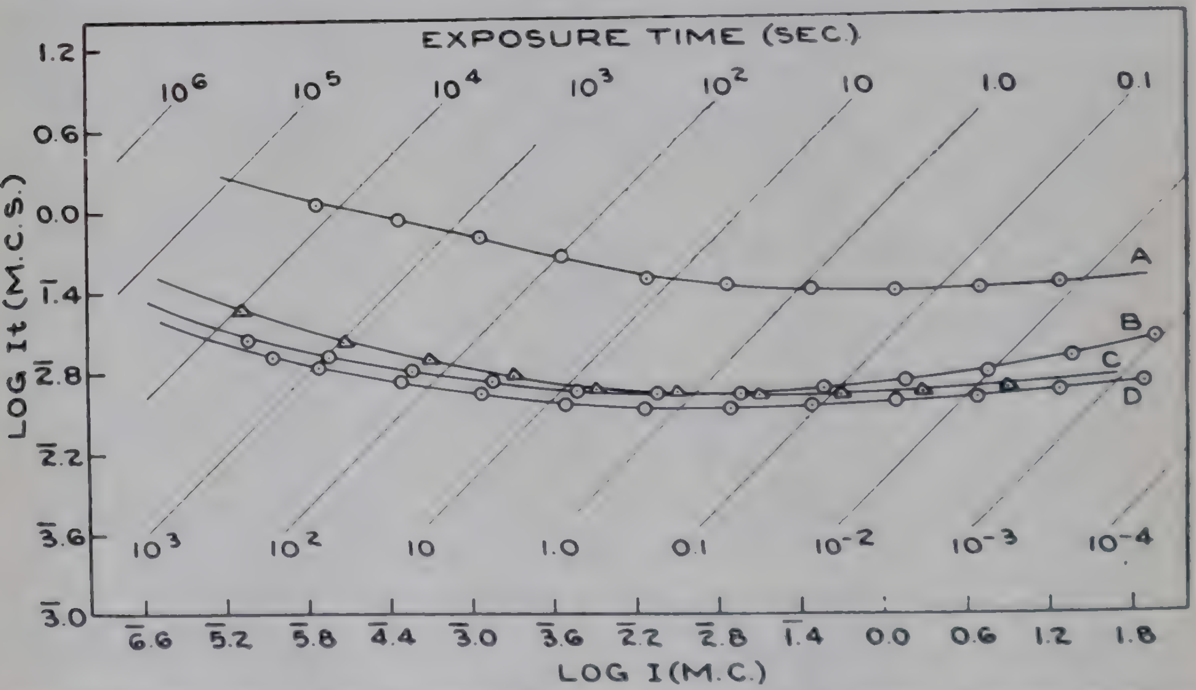


FIG. 13.6. Reciprocity law failure on Eastman plates. *A*, Eastman Process; *B*, Eastman 33; *C*, Eastman 50; *D*, Eastman 40.

this figure, the effect is not great, and over the time usually employed in spectrum photographs (1–100 seconds) the error is not sufficient to interfere with the usual commercial analysis.

Another effect which may influence the accuracy of the spectrographic analysis, termed the *intermittency effect*, is concerned with the variation in density produced by continuous and intermittent exposures of a uniform light intensity for an equivalent total exposure time. The intermittency effect has been shown to be negligible if the interruptions are of the order of 100 per second for a 1-second exposure, and for long exposures the number of interruptions required becomes proportionately less. Harrison (*C100*) has pointed out that for exact spectroscopic work the plate calibration exposure should be made at as nearly the same time and equivalent number of interruptions as the observed spectrogram exposure.

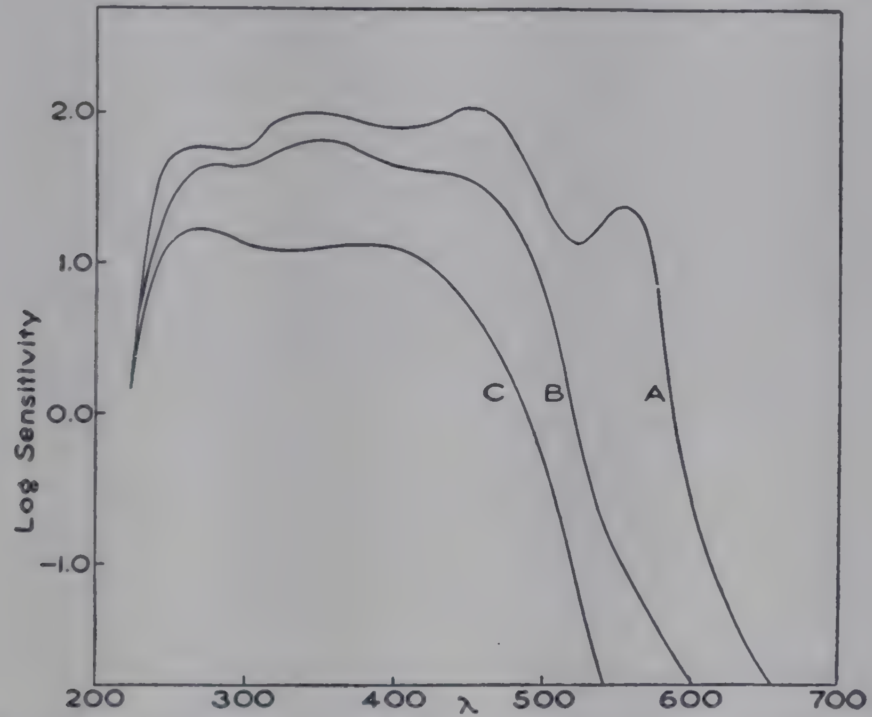


Fig. 13.7. Variation of sensitivity of photographic emulsion with wavelength of exposing source. *A*, panchromatic; *B*, orthochromatic· *C*. process emulsion.

The variation of plate sensitivity with wavelength is an important factor in spectrographic analysis (Fig. 13.7). Plate characteristics for different wavelengths can also be indicated by $d/\log E$ curves for different wavelengths (Fig. 13.13), or by wedge spectrograms (Fig. 13.12).

Developing Process

The developing process involves the use of a suitable reducing agent which will convert the latent silver halide to metallic silver, and the removal of the unaffected silver halide by a suitable solvent or fixing agent. As in the exposure of the silver halide, the development is preceded by an induction period. This induction period has been taken as a means of calculating the proper developing time in accordance with a formula by Watkins:

$$T = W \times T_a$$

where T is time for the production of proper density, T_a the time for first appearance of the image, and W a constant for the developer (including developing temperature). This method of factorial development may be roughly applied to the common metol-hydroquinone developer by the use of a factor 10 to 12 times the time of first appearance of the image.

Nearly all the common developers contain, in addition to the organic developing agents, sodium sulfite or bisulfite, and sodium carbonate or hydroxide. The sodium carbonate or hydroxide acts as a solvent for the phenolic types of organic developers. With the introduction of basic developers, such as *para*phenylenediamine, it is possible to change the pH to a more nearly acid condition. The true action of the sulfite is somewhat uncertain, although there is some evidence of its acting in part as a regenerator of the organic developer after oxidation and as a stabilizer of the reducing developer to prevent oxidation by the oxygen in the air.

For general student spectrographic work it is suggested that the *Eastman 33* or *Eastman Polychrome* plates be used, and that development be made with an accepted metolhydroquinone formula such as:

METOL-HYDROQUINONE DEVELOPER

	(*Agfa 20*)	(*Eastman D-19*)
Hot water (52° C)	1500 ml	1000.0 ml
Metol (elon)	4 grams	4.4 grams
Sodium sulfite, anhydrous	50 grams	192.0 grams
Hydroquinone	8 grams	17.6 grams
Sodium carbonate, monohydrated	36 grams	96.0 grams
Potassium bromide	4 grams	10.0 grams
Water to make	2 liters	2.0 liters

Dissolve chemicals in order given. Use without dilution at 65°.

For accurate quantitative spectrographic analysis, tray development (5–8 minutes at 65° F or 18° C) should be used; the time should be increased by 25 per cent for tank development. Greater and lesser contrast may be obtained by developing for a longer or shorter time than indicated. In high-speed quantitative analysis where a developing time of 1 or 2 minutes is desirable it is suggested that the spectrographic analysis plate be developed in *Eastman D-8* developer.

SINGLE SOLUTION HYDROQUINONE-CAUSTIC DEVELOPER
(*Eastman D-8*)

Water	1.5 liters
Sodium sulfite, anhydrous	180.0 grams
Hydroquinone	90.0 grams
Sodium hydroxide (caustic soda)*	75.0 grams
Potassium bromide	60.0 grams
Water to make	2.0 liters

* Cold water should always be used when dissolving sodium hydroxide (caustic soda) because considerable heat is evolved. If hot water is used, the solution will boil with explosive violence and may cause serious burns if the hot alkali spatters on the hands or face.

Dissolve chemicals in the order given. Stir the solution thoroughly before use.

For use, take 2 parts of stock solution and 1 part of water. Develop about 2 minutes in a tray at 65°F (18°C). This formula is especially recommended for making line and halftone screen negatives for printing directly on metal.

Wash thoroughly after developing and before fixing, or stains and dichroic fog will result.

The *D-19* or *Agfa-20* developer will keep satisfactorily for several months if stored in a full bottle. It is thus advisable in the preparation of a stock of this developer in a solution form to bottle it in several bottles rather than in one large container. The *D-8* developer will not keep satisfactorily for more than two months in a full bottle.

In the development of the student's *Eastman 33* plate in qualitative experiments and in many of the quantitative measurements, it has been found that the *M-Q* tube developer is satisfactory (see page 294). Developing time at 70°F will be about 3 minutes.

In all developing processes, including both plates and paper, care should be taken that the negative or paper is completely and uniformly covered with the developing solution and that no air bubbles remain attached to the surface of the emulsion. If the tray of developer is lifted slightly on one edge so as to flow the developer to the other side of the tray and the negative inserted into the developer and the tray edge lowered, the developer will flow back over the negative to the other side. If the adjacent edge is now raised and lowered, the developer will flow at right angles to the first direction of flow and should completely and evenly cover the negative. Care should be taken not to touch or scratch the emulsion side and to hold the negative by the edges when it is necessary to handle it.

After complete development the negative or paper is transferred to a short-stop tray which contains about the same amount of liquid as the developer tray, 250 ml for an 8 by 10 inch tray. This short-stop for negatives and paper prints should contain about 2 ml of glacial acetic acid. More of the short-stop acid will be necessary for paper prints since it is designed to neutralize the carbonate or alkali from the developer before the print is introduced into the acid hypo or fixer bath. In the development of fine-grain negatives, especially during hot weather, one may find the use of chrome alum short-stop (3 grams potassium chrome alum, 3 grams sodium bisulfite, 250 ml water) or *Eastman Stop Bath* (*SB-3*) of advantage. The negative should remain in the short-stop for about 30 seconds (paper prints about 1 minute) before being placed in the fixing solution. Where speed is desirable it may be satisfactory to omit the stop bath and merely use a water rinse prior to the fixing bath.

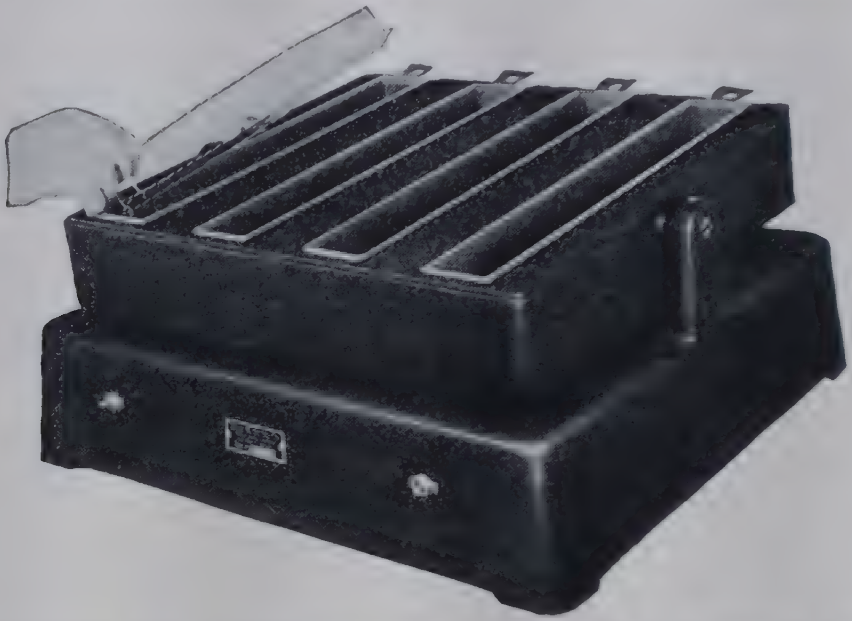


FIG. 13.8. Spectrum film developing equipment (Applied Research Laboratories—Dietert).

The fixing bath (*Eastman F-5*) should be prepared according to the following directions, the chemicals being dissolved in the order given:

FIXING BATH (*Eastman F-5*)

Water, about 125°F (50°C)	1200.0 ml
Kodak sodium thiosulfate (hypo)	480.0 grams
Kodak sodium sulfite, anhydrous	30.0 grams
Kodak acetic acid (28%) pure)*	96.0 ml
Kodak boric acid, crystals†	15.0 grams
Kodak potassium alum	30.0 grams
Cold water to make	2.0 liters

* To make 28 per cent acetic acid from glacial acetic acid, dilute 3 parts of glacial acetic acid with 8 parts of water.

† Cyrstalline boric acid should be used as specified. Powdered boric acid dissolves only with great difficulty, and its use should be avoided.

Films or plates should be fixed properly in 10 minutes (cleared in 5 minutes) in a freshly prepared bath. The bath need not be discarded until the fixing time (twice the time to clear) becomes excessive, that is, over 20 minutes.

Negatives should remain in the fixer for at least 10 minutes after the last visual trace of silver halide has disappeared. Prints should fix completely in 10 to 15 minutes. In the fixing of a number of prints one should move them about from time to time so as to avoid the stoppage of the fixing action which may be caused by two paper surfaces in contact.

Agitation of developer and fixer is essential for even developing and fixing and is best accomplished by gentle rocking of the tray during the process. Agitation is more essential to development than to the fixing process. Care should be taken in the rocking of the tray to avoid what might be termed a standing wave which is produced by the regular rocking of the tray. This can be avoided by irregular rocking of the tray in different directions or by the use of a brush technique in keeping the developer in irregular motion over the emulsion.

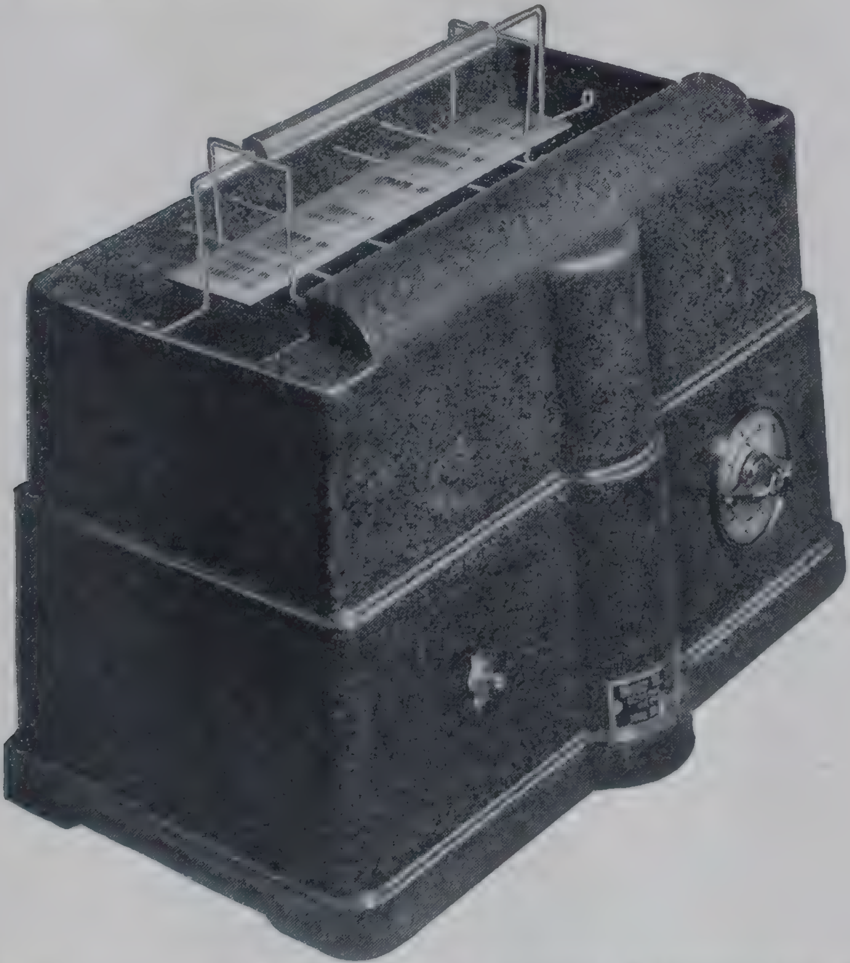


FIG. 13.9. Spectrum plate dryer (Applied Research Laboratories—Dietert).

The completely fixed negative or print should be transferred to a washing tray and washed in a slow stream of water at 18 to 21° C (65 to 70° F) for 15 to 20 minutes. The use of water which is warmer than this temperature range may cause the emulsion to soften unless it has been previously hardened. Colder water than this range will harden the gelatin and slow down the water penetration and thus necessitate a much longer washing period to remove all the hypo. After washing, the negative should be wiped with a soft, wet viscose sponge or cotton pad to remove surface dirt; this is especially true if hard water is used and a scum of calcium salts forms on the film surface. For rapid drying, the plate may be wiped with a moist viscose sponge, from which nearly all the water has been pressed out, before it is placed in the drying rack. Rapid drying of films and plates may be effected by means of heat or radiating lamps provided that sufficient ventilation is supplied to prevent melting of the gelatin (*C201*). Prints should be dried between blotters or on ferrotype tins. The process in both methods of drying can be accelerated by an electrical drying unit.

SAFELIGHTS

The choice of the negative emulsions (*Eastman 33* or *Eastman Spectrum Analysis No. 1*) in the experimental section was based in part on its ability to be used with a No. 1 Wratten safelight and thus permit its development to be more easily observed in class or student demonstrations. One should be certain that the proper safelight filter for the negative or emulsion has been inserted in the safe lamp, and, in case of doubt, especially with the panchromatic type of emulsion, it is advisable to use no safe lamp but to develop in total darkness on a time basis. In the preparation of a safelight filter one should remember that many red dyes or filters transmit a considerable amount of blue or near ultraviolet and the apparent dark red color of a filter is not a guarantee that the filter will be suitable as a photographic safelight.

The amount of light that can be safely permitted in the development of bromide enlarging paper is considerably greater than most workers are accustomed to use. As with photographic emulsions on film or negative base, one must be certain that the safelight filter has a sufficiently sharp absorption band in the yellow and continues to absorb in the near ultraviolet. When there is doubt about the suitability of the safelight, the following test may be performed: cover half of a small piece of film or paper and expose the uncovered half to the safelight for a period of 2 minutes (the usual developing time in front of the safelight). Then develop for 1½ to 2 minutes in darkness or with the emulsion side down in the tray. (N.B.: in normal development of films, plates, and paper always develop with the emulsion side up in the tray.) If the exposed half turns gray the safelight should not be used with that emulsion. It may be that a lamp of lower wattage in the safelight will reduce the fog sufficiently to permit the use of a given safelight filter.

ENLARGEMENTS

Enlarged prints for study or for reproduction purposes are best produced by means of a contrast glossy bromide paper such as *Eastman News Bromide* (Contrast) or *Agfa Brovira* (Single-Weight Contrast). The exposure for an enlargement should be controlled by the lens diaphragm or by the time so that the developing time will be approximately $1\frac{1}{2}$ to 2 minutes for the production of full-scale tones. For greater contrast the exposure should be shorter and development time longer, or an extra amount of potassium bromide may be added and a longer exposure and development given to the print.

An objection to the use of paper enlargement for the measurement of line positions arises out of the uneven shrinkage of a paper print after exposure and before measurement. A special type of photographic paper has been developed for the reproduction of maps by the enlarging process (*Agfa Mapping Special* or *Eastman Aero Mapping Paper*) in which nearly all shrinkage has been eliminated by special treatment of the paper stock. This paper with a high-speed bromide emulsion is well suited for the production of spectrogram enlargements for line identification by direct measurement.

For development of photographic enlargements the *M-Q* tube developer may be used, or the following formula is recommended (*Agfa 125* or *Eastman D-72*):

STANDARD BROMIDE PAPER DEVELOPER

Stock Solution

Metol (Elon)	6 grams
Sodium sulfite (anhydrous)	88 grams
Hydroquinone	24 grams
Sodium carbonate (monohydrated)	130 grams
Potassium bromide	4 grams
Water	2 liters

For use dilute 1 part of stock solution with 4 parts of water. Normal developing time, $1\frac{1}{2}$ to 2 minutes at 21°C (70°F).

In the preparation of photographic prints it is recommended that the paper be handled with nickel, hard rubber, or wood tongs, care being taken that the developer tongs do not touch the hypo or short-stop solutions. The fingers are thus kept dry in the handling of the unexposed and exposed paper.

PHOTOGRAPHIC DARK ROOM

Figure 13.10 is a dark-room plan which has been found to be satisfactory for routine analysis and group instruction (Fig. 13.11). Two safelights are provided, *SL*-1 and *SL*-2, so that bromide prints and negatives can be worked without the necessity of changing safelight filters. The safelight switches should be placed on the wall immediately above each light so that they can be easily reached and turned in the dark. The developer (*D*), short-stop (*S*), and fixer (*F*) trays are indicated in their proper order, with the final wash tray (*W*) in the right-hand sink (*SK*). Immediately above the right side of the sink should be placed a paper-towel holder (*T*). It is desirable to keep a continuous flow of water in the sink so that one can easily wash his hands and obtain a towel without touching a faucet. It is particularly essential that hypo should not be spilled or dropped on the table or floor, and hence the hypo tray should be placed adjacent to the sink; the hand should be washed immediately whenever it has been in the hypo. Although it is possible to turn on the room lights about 1 minute after putting a print or negative into the hypo tray, one should avoid picking the negative or print out of the tray to examine it on account of the danger of dropping hypo. The best practice is to let the negative or print fix in its normal reaction time and wash

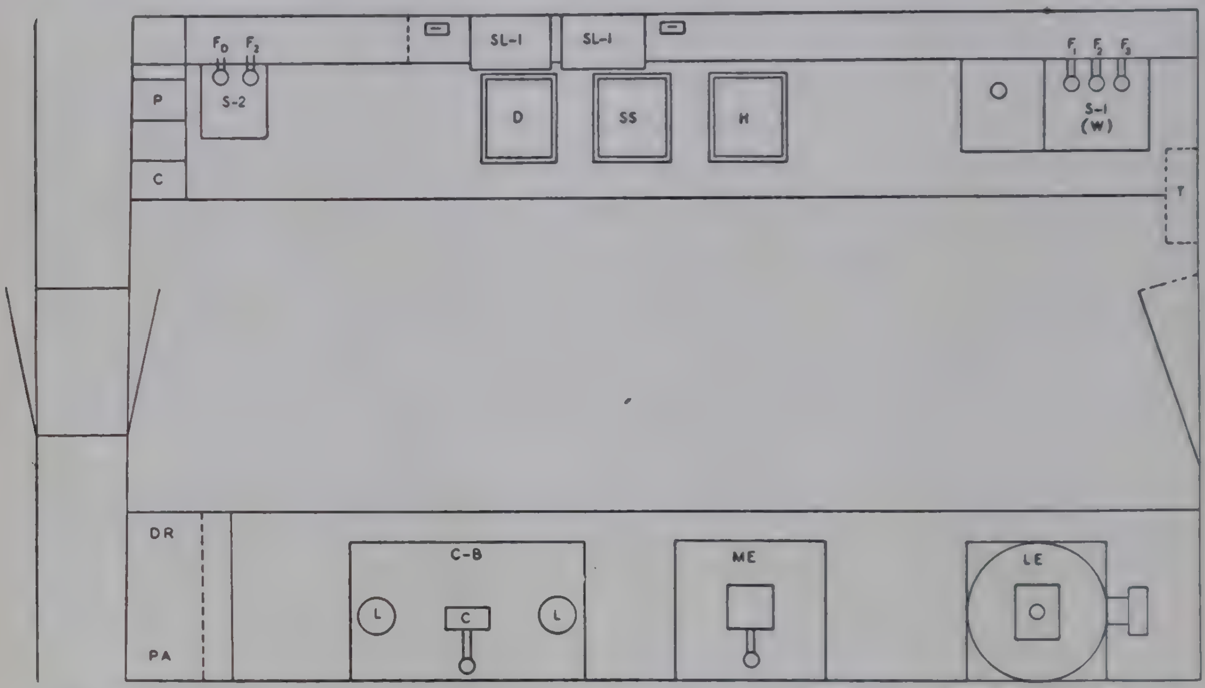


FIG. 13.10. Photographic dark room showing (upper side) developer tray (*D*); short-stop tray (*SS*); hypo tray (*H*), wash tray (*W*) (in sink); safelights (*SL*-1 and *SL*-2) with switches at side of each; sinks (*S*-1 and *S*-2), (note cold [F_1], hot [F_2], and ice [F_3] water at *S*-1 with mixing faucet to maintain uniform temperature of water at 65°–70°F); paper towel rack (*T*) next to sink. Above *S*-1 are shelves for trays and developers; above *S*-2 are shelves for plates and absorption cells: (lower side) enlarging machine for 10-inch negatives (*LE*), interchangeable miniature and small film enlarger (*ME*), copy stand (*C-B*), plate drying rack (*DR*) and shelves for enlarging paper (*PA*). Below table tops on each side are shelves for developers and special materials.

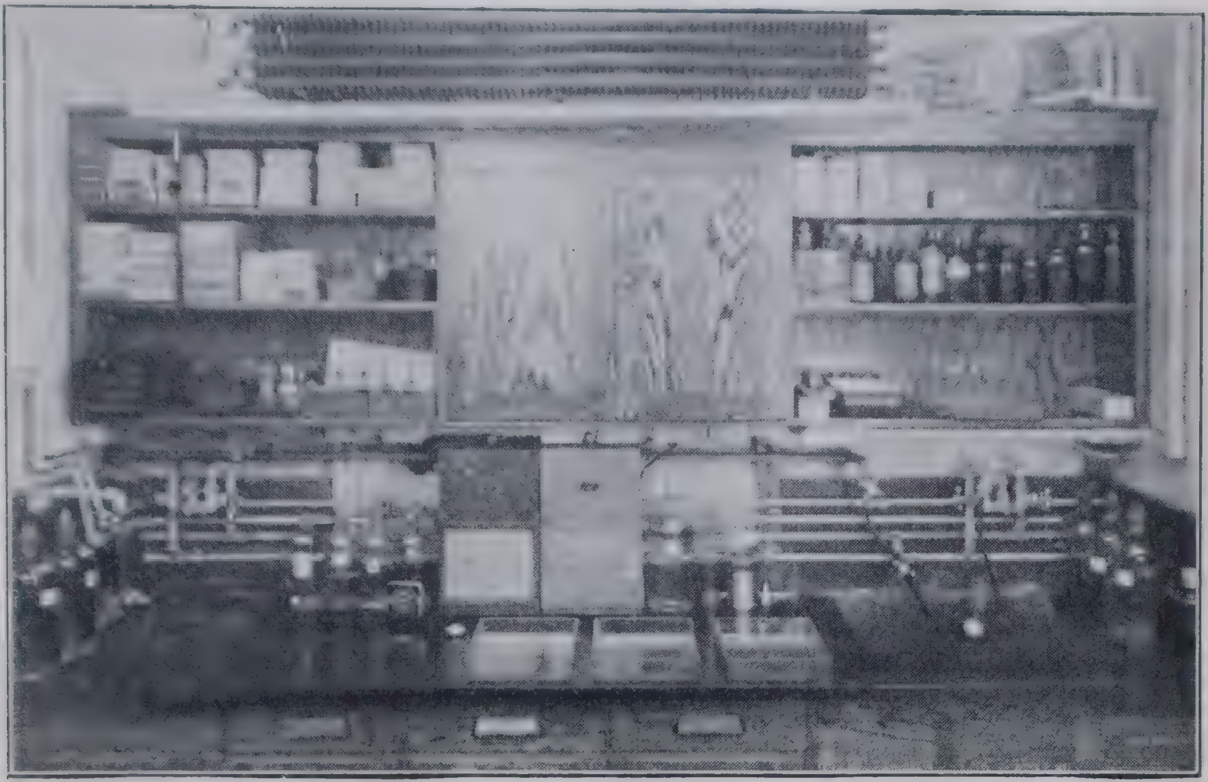
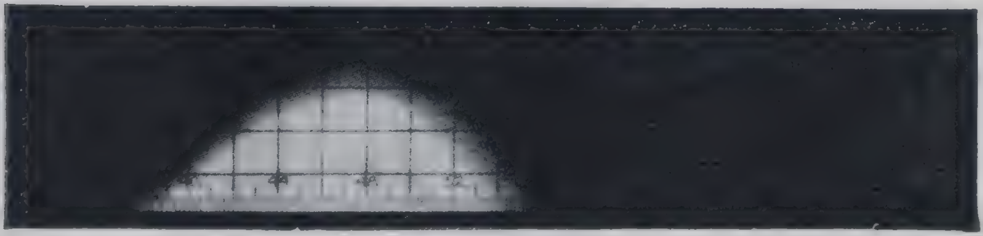
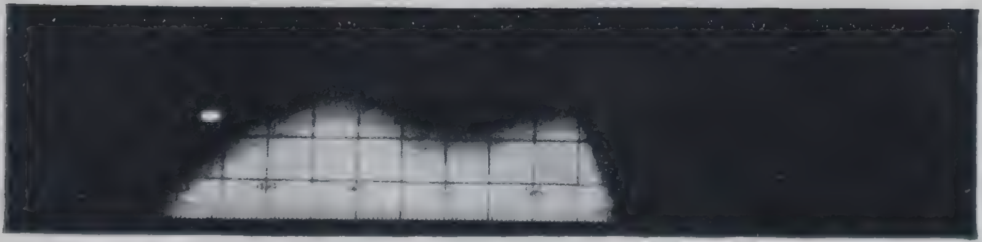


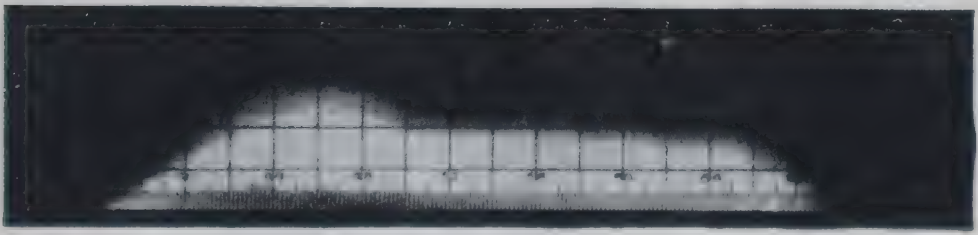
FIG. 13.11. Developing side of dark room indicated in Fig. 13.10.



Ordinary



Orthochromatic



Panchromatic

FIG. 13.12. Wedge spectra of photographic emulsions (Eastman Kodak [*C132*, *D12a*]).

it thoroughly before holding it up for close examination. The principal reason for this care with hypo is not on account of any corrosive action that hypo might have, but rather that hypo when it dries forms an efflorescent powder which will get into the air and will settle on negatives, plate holders, paper, and other apparatus that may come in contact with the sensitive emulsion, with resulting white dots or hypo marks in the final print or negative.

Suitable enlarging equipment should be included in the dark room. Though not necessary, an enlarger capable of taking a regular 4 by 10 negative may be very useful in making reproductions of entire negatives. More useful, however, is a universal enlarger capable of taking negatives from the miniature size (35 mm) to about 4 by 5 inches. The Kodak Precision Enlarger with interchangeable enlarging heads permits this range so that a limited portion of a spectrum negative can be enlarged to ten times or more, or the entire 10-inch spectrogram can be enlarged to three or four times the original size by using three or four sections and 10-inch strips of paper.

It has been found very convenient, and in hot weather almost a necessity, to have running ice water (supplied from a drinking-fountain cooling system) and an air-conditioning unit in the dark room.

SPECIAL PLATES AND EMULSIONS

For the study of certain spectral regions or for special problems involving speed or fine-grain qualities a wide variety of plates are available. The *Eastman 33* plates are not light-sensitive above about 550 mμ, and for observations above this limit orthochromatic or panchromatic negatives must be used, with the corresponding change in safelight or complete elimination of a safelight and development in the dark on a

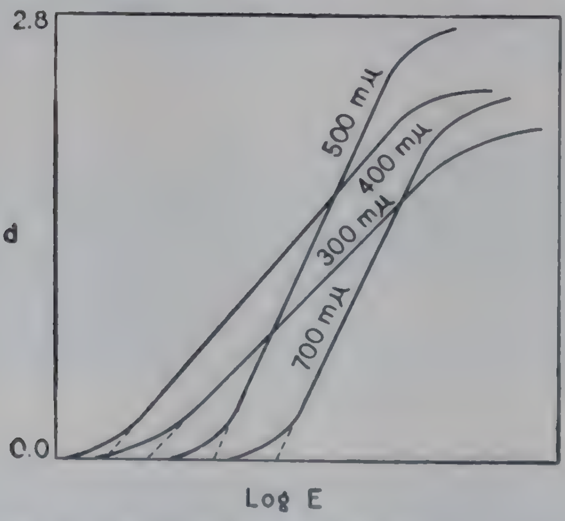


FIG. 13.13. Variation in chromatic sensitivity for panchromatic emulsion.

time basis. Figure 13.12 indicates the wedge spectra of some of the common types of Eastman emulsions. In Fig. 13.13 are given the $d/\log E$ curves for a panchromatic emulsion for four wavelength values. (See Fig. 5.15). It should be noted that the negative indicated in this figure

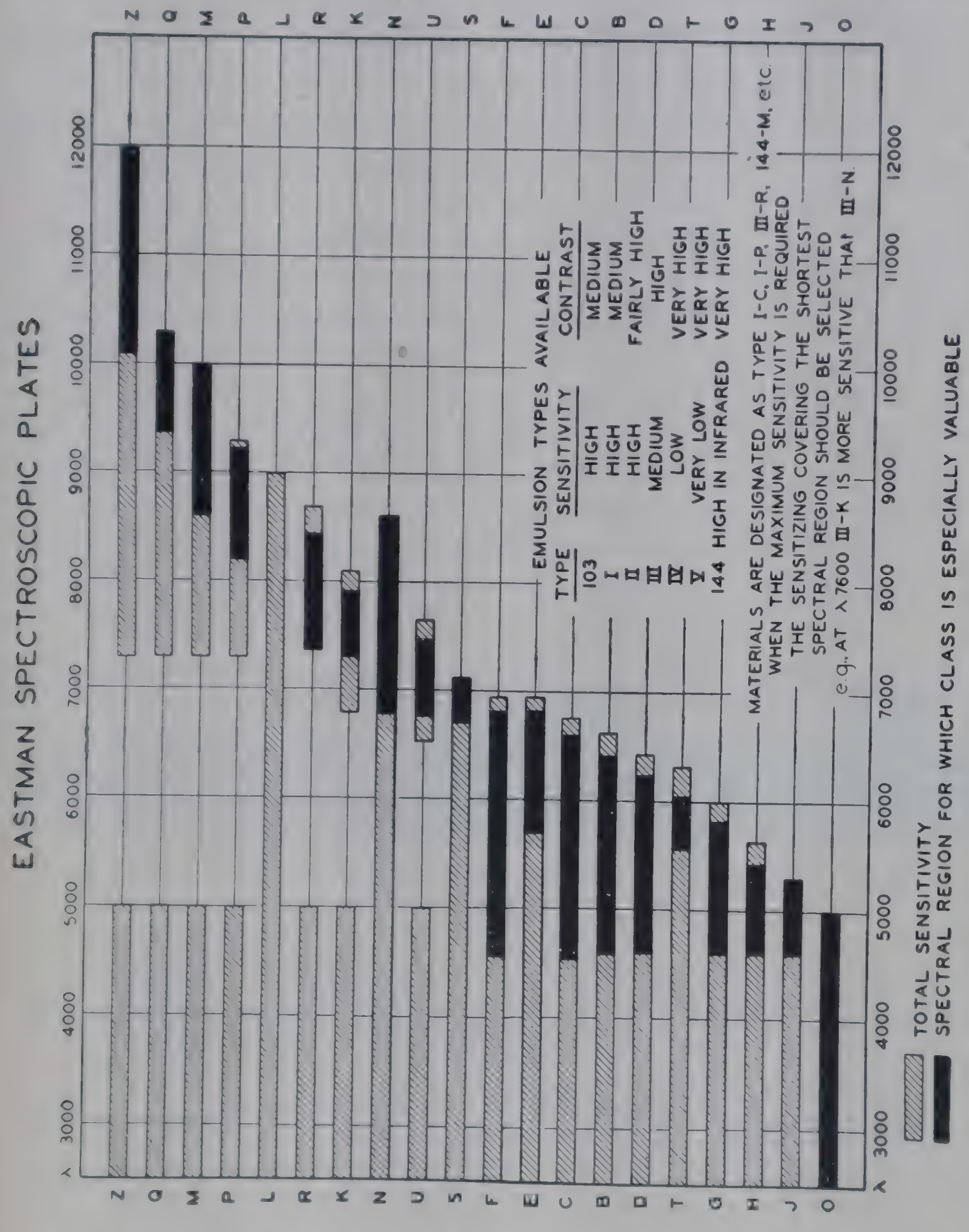


FIG. 13.14

does not have a uniform spectral response, and this should be considered in the application of density calibration patterns on a negative as a means of obtaining relative line intensities in terms of an absolute standard. The theoretically correct application of a calibrated wedge would involve the illumination of the wedge photograph with approximately the same wavelength of light as produces the line which is to be measured. The calibration pattern can be applied in this manner through the use of a Hansen step slit, a gradient or step absorbing wedge, or a rotating sector in front of the slit of the spectrograph. It would be preferable to illuminate the slit with a heterogeneous or continuous spectral source, but a wide slit may be used without much distortion so as to produce a nearly continuous spectrogram from a line source such as an iron arc.

Mees (*C 132*) has recently published (Fig. 13.14) information on a number of special Eastman emulsions which have been prepared for spectroscopic measurements in the infrared. The sensitivity of these emulsions extends the photographic range to about 1200 or 1300 mμ.

The absorption of the gelatin emulsion below a wavelength of 2500 A influences the density which can be obtained, and below 2000 A this absorption is sufficient to absorb the ultraviolet light almost completely before it can affect the silver halide particles.

The preparation of silver halide plates free from gelatin, or containing only a small amount, permits spectrophotographs below 2000 A. Such plates are known as Schumann plates. They are extremely difficult to make, and the delicate nature of the halide film makes them difficult to handle. One method of preparation of these Schumann plates has been to use an ordinary gelatin plate and dissolve the gelatin in sulfuric acid so as to leave the silver halide with only a mere trace of gelatin binder. A second method of photographing in extreme ultraviolet has been to coat the gelatin emulsion with a fluorescent substance so that the line of lower wavelength will react upon the fluorescent material to produce an emission of higher wavelength such as will penetrate the gelatin emulsion. The plate is usually bathed with a solution of the fluorescent material and allowed to dry, and the exposure is made in the usual manner. After exposure the ultraviolet sensitizer is washed off the plate (ethylene chloride is used as the washing solvent for the ultraviolet sensitizing solution) and the plate developed in the usual manner (Fig. 13.15).

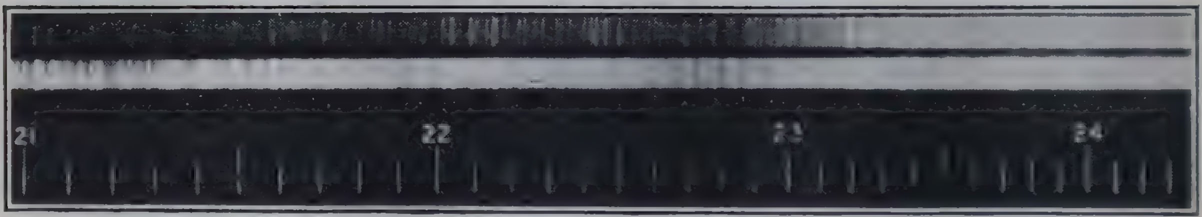


Fig. 13.15. Photograph of the ultraviolet spectrum on ordinary and sensitized emulsion (Eastman ultraviolet sensitized).

By careful selection of the quartz material used in a quartz spectrograph, ultraviolet transmission may be obtained down to about 1800 A; however, the usual instrument is seldom calibrated below 2000 A and in many cases a part of the drop in sensitivity at the low-wavelength end of the plate may be due to absorption of the quartz as well as the gelatin emulsion. In addition to the spectrum plates indicated in Fig. 13.14, there is also available an *Eastman Spectrum Analysis Plate* which has been prepared for use in metallurgical spectrographic analysis. This plate has a higher contrast than the usual process plate, low background density, and adequate sensitivity, and it is suitable for very rapid processing. The low background density makes it desirable for use with a densitometer for the measurement of line densities (Fig. 13.2*b*).

For observations in the red and infrared portion special negatives are required as indicated in Fig. 13.14, and in addition it is possible to hypersensitize negatives by bathing the plate in a 1 per cent ammonia solution. These hypersensitive plates should be used within a few days after the ammonia treatment.

Where high speed of emulsion or certain spectral characteristics are desired one should consult the published data of the Eastman Kodak Company and the Agfa Ansco Corporation (*D12*, *D13*). For extremely high speed and fine grain, especial attention is called to the *Agfa Ultra* and *Superpan Press* films and *Eastman Tri-X Panchromatic Film*. Most of these special films require time development in total darkness with special developers which are indicated on the package of film.

DIRECT POSITIVE SPECTROGRAMS

As has been pointed out in the introduction (page 5), there is a lack of agreement among spectroscopists as to the method of presentation of spectrograms in a publication. In many cases the publication of negative (**N**) spectrograms is avoided because of the necessity of making a negative from the original negative (**N**) spectrogram and making the positive print from this second negative. Direct positive paper and films are available, and their application to spectrographic work permits the direct preparation of a negative print without going through the intermediate positive reproduction. While the reversal process is quite commonly applied to plates and films, it may also be applied to bromide paper emulsions or special *Direct Positive Paper* (Eastman). The process involves (*a*) exposure, (*b*) development of negative, (*c*) bleaching of negative, (*d*) clearing, (*e*) re-exposure, (*f*) redevelopment, (*g*) fixing; and after each solution it is necessary to wash the print thoroughly. The entire process can be completed in 5 minutes, and except for the care required in giving the correct initial exposure there are no difficult or troublesome steps in the manipulation. Specific directions for developers are usually contained in the packages of special papers prepared for direct positive printing. The papers provided are sufficiently sensitive to use as enlarging papers, and quite satisfactory negative enlargements of negatives can be made by this process.

Special emulsions are available for direct reproduction of negatives in a negative form. Nearly all the amateur motion-picture film is processed by this reversal method so as to provide a positive in place of a negative film. High-speed emulsions are available for this purpose, and it is possible to use them directly in the spectrograph so as to obtain as the original spectrogram a positive rather than a negative, from which direct negative enlargements can be made. Reversible film may also be used in the reproduction of negatives in a negative form as indicated above in the direct positive paper process. More satisfactory results can be obtained in the direct reproduction of negatives as negatives by the use of *Agfa Direct Copy* and *Eastman Autopositive Commercial* film. This film has been given a preliminary exposure such that the film if developed directly would give a maximum gamma. As can be seen in Fig. 13.3, the continued exposure of an emulsion will result in a destruction of the latent image. The exposure of this special film in the ordinary printing process results in a destruction of the latent image, and by usual developing processes one obtains a negative copy of the negative or a direct copy of the original film.

An advantage of this process over the use of an intermediate positive negative and such film bases as are commonly employed in commercial reproduction lies in the ability of the direct copy film to produce a gamma which is almost identical with the original negative so that relative line intensities will not be appreciably altered by this process.

Literature

C. B. Neblette, "Photography, Its Principles and Practice" (*B62*).
C. E. K. Mees, "Photography."
W. D. Morgan, "The Leica Manual."
C. E. K. Mees (Eastman Kodak Company), "Plates for Spectroscopy and Astronomy" (*D12a*).
J. E. Crabtree and G. E. Matthews, "Photographic Chemicals and Solutions."
H. M. Lester, "Photo-Lab-Index."
Publications by the Eastman Kodak Company and the Agfa Ansco Corporation on photographic materials (*D12, D13*).

CHAPTER XIV

EQUIPMENT AND ARRANGEMENT OF A SPECTROGRAPHIC LABORATORY

Choice of Equipment

In the organization of a spectrographic laboratory one should be aware of the fact that the expensive spectrographic instruments are usually of such a nature as to be permanent equipment. With careful and proper treatment, spectrographic equipment will outlast the usual life span of the laboratory building or the workers who use it. The initial cost may thus be considered as an investment, with the actual cost of the laboratory figured as the sum of the operation expense and a reasonable amortization of the investment over an extended period of time.

The choice of equipment will naturally depend upon the funds and space available and the use which is to be made of the equipment. Since each will be a special case, one can only advise in a general way with regard to equipment and arrangement. For routine qualitative emission analysis on reasonably large samples the *small* type (Fig. 3.4) should be satisfactory for those elements producing a relatively small number of spectrum lines (tin, lead, silver, zinc, cadmium, magnesium, aluminum, etc.). With an increase in the number of lines, either through the increase in the number of elements or the introduction of elements giving a larger number of lines (such as iron cobalt, nickel, manganese, molybdenum, platinum, titanium, etc.), higher resolution is necessary to separate the lines effectively for identification purposes. It is difficult, of course, to set any exact limits to the various instrument types. For example, if the amount of iron present in a zinc alloy is so low that only the persistent lines of iron are present, then high resolution and increased dispersion are not essential. The resolution obtained on a medium spectrograph may not be sufficient. For the examination of such samples and steels or other compounds producing complex spectra an instrument with a focal length of at least a meter should be employed. Such instruments in the prism type are usually of a Littrow design and in the grating type may be either Eagle or Roland mounted.

The application of quantitative methods, either densitometer or logarithmic sector, will require about the same resolving power as is necessary for the qualitative identification. If the amount of material available for examination is small, then high light-gathering power of the spectrograph becomes an important factor. In general, the smaller spectrographs have greater light-gathering power, i.e., the ratio between the focal length and the lens diameter or prism aperture, and it would be a mistake to obtain a large *Littrow* type of spectrograph with the idea that the larger the instrument the more delicate or sensitive would be the photographic response to traces of the unknown. Quartz prism instruments are dependent upon the available supply of natural quartz crystal, which is certainly limited in amount. The difficulty in obtaining highly transparent quartz crystals free from twinning and other defects, and of sufficient size for use, is one of the factors which markedly affect the sale price of the finished instrument.

Improvements in recent years in the ruling of gratings on glass and the application of aluminum reflecting films to such surfaces have increased the accessibility and usefulness of gratings. Although the majority of present-day spectrographic instruments are of a prism type, there can be little doubt that the science of spectroscopy is passing through the prism era and approaching a grating era. Replica gratings can be produced in plastic material, and for many purposes adequate dispersion and resolution can be obtained from these casts taken from a master ruled grating. The gratings produced by Professor R. W. Wood of Johns Hopkins University are of an unusually high quality, the technique of ruling being developed to such a degree that it has been possible to rule a grating which will concentrate the majority of the spectral reflection in a given order and on a given side of the normal. The accuracy with which new types of organic plastics can be cast into prism, lens, and grating form, without distortion, will undoubtedly open the way for the production of spectrographic instruments, of both prism and grating type, at a considerably lower cost, provided that sales will be sufficient to justify quantity production. Several grating instruments are now available in a convenient laboratory form including original and replica grating dispersion parts (Baird, Hilger, Central Scientific, Jarrell-Ash, and Applied Research Laboratories—Dietert). The optical principle of the grating instrument does not permit the use of a Hartmann diaphragm or logarithmic sector at the slit. The optical system can be altered, however, so as to permit the use of a logarithmic sector or a wedge for superimposed spectrograms. This is accomplished by placing the sector or horizontal diaphragm at the secondary astigmatic focus.

In the field of absorption spectra analysis, instruments for visual color analysis should be considered separately from ultraviolet equipment. The manually operated types, such as the Bausch and Lomb, Hilger, Gaertner, or König-Martens, are particularly useful for color control and quantitative application to colorimetric reactions. The much more expensive Hardy-General Electric spectrophotometer is more rapid and accurate than the manually operated types.

Ultraviolet spectrophotometers for the determination of absorption spectra are available from most of the concerns which specialize in spectrographic equipment. Some of these are of a diaphragm type (Hilger-Spekker, Hilger-Judd Lewis, and Kipp and Zonen), some are of a sector type (Bausch and Lomb, Hilger, Zeiss, Dietert, and Gaertner), and others are of a polarizing type (Bellingham Stanley, Jobin and Yvon, Schmidt and Haensch).

In recent years a number of spectrophotometers have been introduced utilizing photronic or photocells to measure light intensity. Among these are instruments produced by Coleman, Beckman (National Technical Laboratories), Cenco-Sheard, American Instrument, Klett, and Photovolt.

Most of these instruments are designed to be used with spectrographs of the same manufacture although they can usually be adapted to other makes of spectrographs. It is essential in both emission and absorption apparatus that the alignment and adjustment should be simple to maintain and operate, and for this reason most of the instrument-makers are producing instruments with an optical bench for light sources and photometers attached as an integral part of the spectrograph.

No definite recommendations can be made in a general textbook as to any one make or type of instrument since so many factors must influence the choice. The production of properly ground prisms, slits, gratings, and lenses, like that of other fine optical instruments, is an art requiring unusual skill, and, hence, the number of producers of satisfactory spectrographic equipment is limited. Nearly all of them maintain a competent staff of technicians to aid and advise with respect to required equipment for a given problem. If one is planning to establish such a laboratory, the advice of research or academic workers connected with universities, government laboratories, or private research and testing laboratories should be sought.

Conditions make it difficult to provide an accurate list of manufacturers of spectrographic equipment. A partial list of such manufacturers would include:

Adam Hilger, Ltd., London, England (Jarrell-Ash Company, Boston, and A. H. Thomas Company, Philadelphia, American agents).
Bausch and Lomb Optical Company, Rochester, N. Y.
Carl Zeiss, Jena, Germany (American office, New York).

Gaertner Scientific Company, Chicago.
Jobin and Yvon, Paris, France.
Franz Schmidt and Haensch, Berlin, Germany.
Kipp and Zonen, Delft, Holland.
R. Fuess, Berlin, Germany.
Bellingham Stanley, London, England.
Spencer Lens Company, Buffalo.
Central Scientific Company, Chicago.
Baird Associates, Cambridge, Mass.
General Electric Company, Schenectady, N. Y.
H. W. Dietert Company, Detroit (Applied Research Laboratories).
C. A. Steinheil Söhne, Munich, Germany.
National Technical Laboratories, Pasadena.
Photovolt Corporation, New York.
American Instrument Company, Washington, D. C.
Coleman Electric Company, Maywood, Illinois.
Klett Manufacturing Company, New York.

Suggested equipment and approximate cost:

(*a*) Rough qualitative measurement of the visual spectrum (direct-vision hand or table spectroscope of either prism or grating type, using a flame, arc, or spark source). Cost, $10 to $100.

(*b*) Accurate visual spectrum measurement (spectrometer with suitable light sources). Cost, $50 to $400.

(*c*) Ultraviolet spectrum photography (small spectrograph and suitable sources). Cost, $400 to $700.

(*d*) Ultraviolet spectrum equipment for quantitative analysis and more accurate qualitative analysis (intermediate type of spectrograph). Cost, $600 to $1200.

(*e*) Ultraviolet spectrum equipment for quantitative and qualitative analysis of all types of samples except those with an extremely large number of lines (medium type of spectrograph with suitable light sources, logarithmic sector, etc.). Cost, $1400 to $3000.

(*f*) Ultraviolet spectrum equipment for qualitative and quantitative analysis of substances containing elements producing a large number of lines (grating or Littrow-type spectrograph with suitable light sources, logarithmic sectors, etc.). Cost, $2500 to $5000.

(*g*) Rough visual qualitative absorption analysis (hand or table grating or prism spectroscope). Cost, $5 to $50.

(*h*) Accurate visual quantitative absorption analysis (visual spectrophotometer, including spectrometer, photometer, and suitable light sources and cells). Cost, $1200 to $2500.

(*i*) Photoelectric or photronic instruments for visible and ultraviolet measurement (nonrecording). Cost, $300 to $1000.

(*j*) Automatic photoelectric measurement of visual absorption spectrum (recording instrument). Cost, $3000 to $6000.

(*k*) Minimum equipment for ultraviolet qualitative absorption measurement (small spectrograph with suitable tubes and light sources). Cost, $400 to $700.

(*l*) Minimum equipment for quantitative spectrographic analysis in the ultraviolet (intermediate spectrograph and ultraviolet photometer, cells and light source). Cost, \$1200 to \$1600.

(*m*) Equipment for general quantitative ultraviolet absorption spectrum analysis (medium spectrograph and ultraviolet photometer, cells, and light source). Cost, \$2000 to \$4000.

ASSEMBLY AND DESIGN OF LABORATORY

The spectrographic laboratory should be carefully planned so as to be efficiently operated and capable of being kept in continuous operating condition. Such a laboratory is usually a show place in either industrial or research organizations, and some thought should be given to protection of exposed wires and suitable locking nuts or covers for exposed adjustment screws and slit mechanism. If adequate ventilation is provided over arc or spark sources there should be no trouble from fumes, but if the laboratory is subject to fumes the slit mechanism should be protected and the plate holder or a dummy kept in the rack in the instrument. The maintenance of a well-polished laboratory not only creates a good impression but is essential if accurate analyses are to be made for elemental traces.

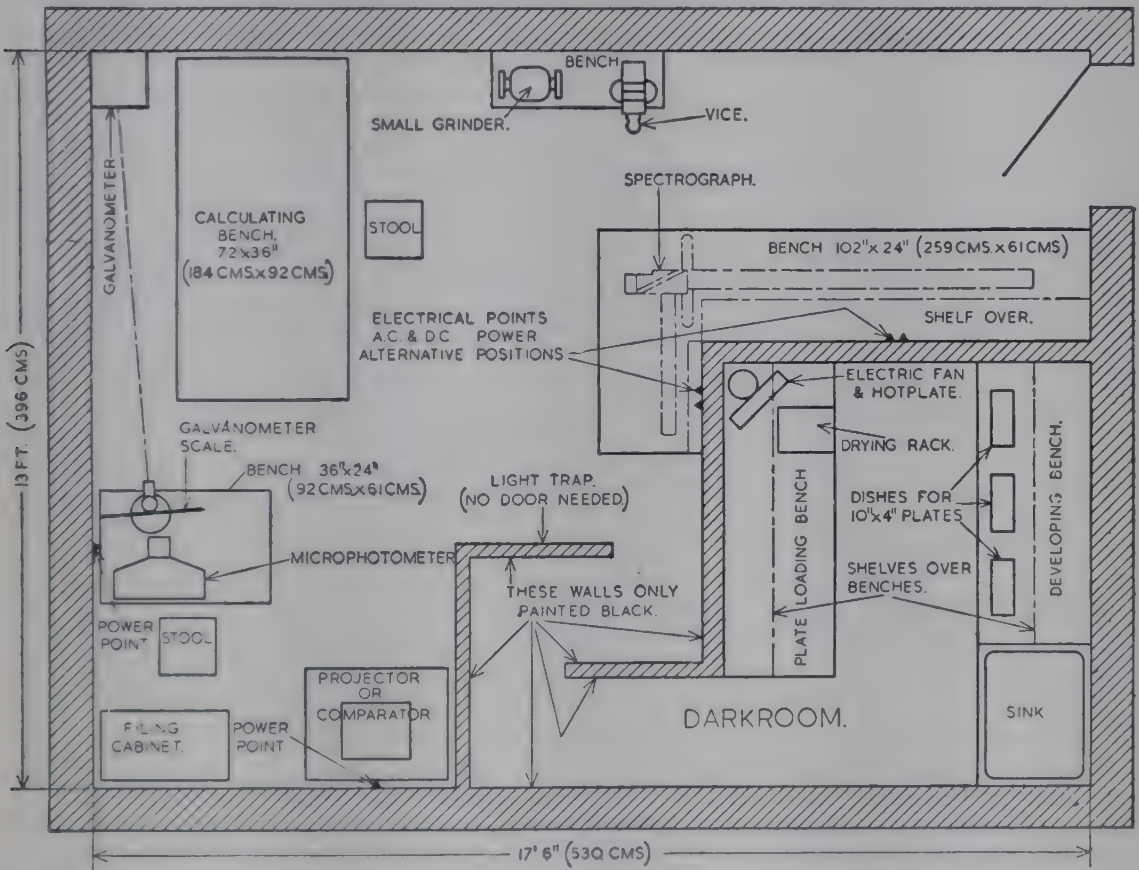


FIG. 14.1. Plan of a spectrographic laboratory (Hilger).

The design of modern spectrographs does not require their operation in a dark or poorly lighted room, and except when certain focus adjustments are being made there is no reason why the laboratory should not be reasonably well lighted. For adjustment purposes one may find it convenient, however, to have placed adjacent to each spectrograph a switch to turn on or off the room lights, and some means of reducing the window light should be provided. In the location of spectrographic equipment, it should be remembered that almost all spectrographs, including grating, and both Cornu and Littrow prism types, are asymmetrical in construction and operate from one side only. Photographs or drawings of the proposed instrument should be consulted before making plans for the laboratory arrangement (Fig. 14.1). Where the analysis equipment involves the photographic process, a dark room should be provided as suggested in Chapter XIII. It is preferable to have a separate room for plate reading, in which suitable tables, charts, plate-reading boxes, and densitometers or projection devices can be operated or used. This same room, which can be darkened, can be easily adapted for visual spectrophotometric equipment.

PERSONNEL

The person in charge of the spectrographic laboratory should have a thorough and intimate knowledge of the operation, adjustment, and calibration of the equipment under his direction. Although a course in spectrographic methods and in theoretical spectroscopy may be of considerable assistance in the solution of problems which are submitted, it is only by continued study and actual laboratory manipulation that one becomes adept at the rapid identification of lines or the matching of beams. A considerable amount of spectrographic analytical work is of a routine nature and can be delegated to a laboratory assistant who has not had any special training in this field of analysis. The interpretation of results, however, should be attempted only by those who have a thorough knowledge and appreciation of the significance of the data obtained.

LIBRARY FACILITIES

Spectrographic analysis is largely dependent upon adequate library facilities in the form of comparison negatives of known elements, standard photographic and printed charts (see Chapter IV), a satisfactory set of spectrum-line tables, and a number of standard reference works in spectroscopic and related fields. In general, these tables, charts, and plates form an integral part of the spectrographic laboratory and should be kept in the plate-reading room or spectrographic laboratory rather than in the library of the laboratory or institution. Special mention should be made of the spectrographic publications of the firm of Adam Hilger, Ltd., which has specialized for several generations in the production of spectrographic equipment and the dissemination of information concerning its use and application. Under the guidance of the managing director, Mr. F. Twyman, F.R.S., the company has published spectrum tables, translations of important books on spectroscopy, and numerous original contributions to the field of spectroscopy, and it provides an abstract service on articles of a spectrochemical nature. As has been mentioned elsewhere in this book, it has prepared numerous spectrum charts and has undertaken to produce and dispense special electrodes for control analysis.

The scientific and technical papers from the Bureau of Standards, especially those by Meggers, Kiess, Coblentz, and Gibson; the *Proceedings* of the annual conferences on spectroscopy, held at the Massachusetts Institute of Technology under the direction of Professor G. R. Harrison (the proceedings are published in the *Journal of the Optical Society of America*); the *Spectrochimica Acta*; and the general reference books and periodicals dealing with spectroscopy should be available in the library of the laboratory or institution.

Operation of the Laboratory

The use of the spectrographic equipment should be strictly limited to those workers who have been properly trained and have the permission of the director of the laboratory to make the desired observations. It is desirable to retain in the laboratory all record sheets and plates, both of which should be filed for future reference. A duplicate copy of the data sheet and a print of the negative may be submitted with the analytical report if they are requested. Since special projection devices, viewing boxes, charts, and tables are required for the proper interpretation of most analytical spectrograms, it should be quite obvious that the plate records must be kept where they can be easily read or the reported results rechecked if necessary.

Standard data sheets, with serial numbering, should be used for recording spectrograms, and great care should be exercised to see that each negative is numbered to correspond to the data sheet and that the individual spectrograms on the negative are properly recorded on the data sheet. Duplicate analyses should be made whenever possible, and the amount of unknown and exposure should be so regulated as to insure satisfactory sampling of the material.

BIBLIOGRAPHY

A. THEORY OF SPECTRA, QUALITATIVE AND QUANTITATIVE EMISSION ANALYSIS (BOOKS)

A1 American Society for Testing Materials. Reprint of papers from a Symposium on Spectrographic Analysis. *Proceedings of the American Society of Testing Materials*, Vol. 35, Part II, 1935.

A2 American Society for Testing Materials. Spectrographic Analysis Specifications. Reprinted from the *Proceedings of the American Society of Testing Materials.*

A3 Babcock, H. D., and Adams, W. S. Solar Spectrum. International Critical Tables, Vol. V, p. 380. (See *A48*.)

A4 Baly, E. C. C. Spectroscopy, Vols. I, II, and III. (In the series of Textbooks of Physical Chemistry.) 3rd Edition. Longmans, Green and Co., Ltd., London, 1927–29.

A5 Bardet, J. Atlas de spectres d'arc. G. Doin, Paris, 1926. Includes 54 charts 7 by 9½ inches.

A6 Bonhoeffer, K. F., and Harteck, P. Grundlagen der Photochemie. Steinkopff, Dresden and Leipzig, 1933.

A7 Bragg, Wm. The Universe of Light. The Macmillan Co., New York, 1933.

A8 Buisson, H., and Fabry, Ch. Spectre du fer, Marseille, Fac. d. Sc. Ann., Vol. 17, 1909.

A9 Candler, A. C. Atomic Spectra, Vols. I and II. Cambridge University Press, London, 1937.

A10 Candler, A. C. Elements of Atomic Spectrum Theory. Adam Hilger, Ltd., London, 1938.

A11 Candler, A. C. Spectrographic Analysis in Great Britain. Adam Hilger, Ltd., London, 1939.

A12 Condon, E. U., and Shortley, G. H. The Theory of Atomic Spectra. Cambridge University Press, 1935.

A13 Crook, W. J. Metallurgical Spectrum Analysis. Also atlas of 24 plates. Stanford University Press and Oxford University Press, 1935.

A14 Crook, W. J. Table of Arc Spectrum Lines Arranged in Order of Wavelength. Stanford University Press, 1933.

A15 Duffendack, O. S., et al. U. S. Patent 1,979,964, 1934.

A16 Eder, J. M., and Valenta, E. Atlas typischer Spektren. A Holder, Wien, 1911–28. Includes 53 cards (12 by 16 inches) with twelve printed spectrograms on each card.

A17 Eggert, J., and Rahts, W. Photography. Handbuch der Physik, XIX. pp. 539–612. (See *A37*.)

Emery, F. H. (See *A36*.)

A18 Eucken, A., und Wolf, K. L. (Editors of Hand- und Jahrbuch der chemischen Physik.) (See *A38*, also Scheibe, Reinkober, Teller, Mecke.)

A19 Exner, F., and Haschek, E. Die Spektren der Elemente bei normalen Druck. Band I (1911). Hauptlinien der Elemente und Codex der starken Linien im Bogen und Funken. Band II (1911). Die Bogenspektren der Elemente. Band III (1912). Die Funkenspektren der Elemente. Franz Deuticke, Leipzig and Wien.

A20 Fabry, Ch. Spectroscopic Standards of Wavelength. International Critical Tables, Vol. V, p. 274. (See *A48.*)

A21 Fabry, C. Introduction générale a la photométrie. Revue d'optique théorique et instrumentale, Paris, 1927.

A22 Foote, P. D., and Mohler, F. L. The Origin of Spectra. The Chemical Catalog Co., New York, 1922.

A23 Forsythe, W. E., and others. Measurement of Radiant Energy. McGraw-Hill Book Co., New York, 1937.

A24 Fowler, R. H. Series in Line Spectra. Fleetway Press, Ltd., London, 1922. Reprinted 1927.

A25 Frerichs, R. Line Spectra. Handbuch der Physik. XXI. pp. 273–328. (See *A37.*)

A26 Gatterer, A., and Junkers, J. Atlas der Restlinien. Specola Vaticana, Castel Gandolfo, Italy, 1937. Tables of the principal lines of 50 elements and 28 photographic charts (12 by 16 inches) with 6 spectrograms per chart.

A27 Gatterer, A., and Junkers, J. Arc Spectrum of Iron from 8388 to 2242 A. (Specola Vaticana) Castel Gandolfo, Hirschwaldsche Buchhandlung, Berlin, 1935.

A28 Gerlach, Wa., and Gerlach, We. Clinical and Pathological Applications of Spectrum Analysis (With Notes on Spectrography in Chemistry and Mineralogy and Tables for Qualitative Analysis). Authorized translation (by F. Twyman) of Die chemische Emissionsspektralanalyse. Vol. II. L. Voss, Leipzig, 1933. Adam Hilger, Ltd., London, 1934.

A29 Gerlach, W., and Riedl, E. Die chemische Emissionsspektralanalyse, Vol. III, Tabellen zur qualitativen Analyse. Leopold Voss, Leipzig, 1936.

A30 Gerlach, W., and Schweitzer, E. Foundations and Methods of Chemical Analysis by the Emission Spectrum. Authorized translation of Die Chemische Emissionsspektralanalyse. Vol. I. L. Voss, Leipzig, 1929. Adam Hilger, Ltd., London.

A30*a* Gibb, T. R. P. Optical Methods of Chemical Analysis. McGraw-Hill Book Co., New York, 1942.

A31 Glasstone, S. Recent Advances in Physical Chemistry. 2nd Ed. P. Blakiston's Son and Co., Philadelphia, 1936.

A32 Glasstone, S. Physical Chemistry. D. Van Nostrand Co., New York, 1940.

A33 Grotian, W. Graphische Darstellung der Spektren von Atomen und Ionen mit ein, zwei und drei Valenzelektronen. Springer, Berlin, 1928.

A34 Hagenbach, A., and Konen, H. Atlas der Emission Spectra. Gustav Fischer, Jena, 1905. English edition by A. S. King; Wesley and Sons, London.

A35 Handbook of Chemistry and Physics, 25th Edition. Editor, C. D. Hodgman. Chemical Rubber Publishing Co., Cleveland, Ohio, 1941.

A36 Handbook of Chemistry, 4th Edition. Editor, N. H. Lange. Handbook Publishers, Sandusky, Ohio, 1941.

A37 Handbuch der Physik. Editor, H. Konen. Vols. XIX and XXI. J. Springer. 1928. (See *A*: Eggert, Konen, Frerichs, Lowe, Mecke; and *B*: Brodhun Ley, Lowe, Frerichs, Dreisch Pringsheim.)

A38 Hand- und Jahrbuch der chemischen Physik. Editors, Eucken and Wolf. Akad. Verlag., Leipzig, 1937. (See Scheibe, Reinkober, Teller, Mecke.)

Handbuch der Spektroscopie. (See Kayser and Konen, *A52*.)

Handbuch der Experimental Physik. (See Wien-Harms, *A109*, *A110*, *A111*.)

A39 Harrison, G. R. M.I.T. Wavelength Tables of 100,000 Spectrum Lines. John Wiley and Sons, New York. 1939.

A40 Harrison, G. R. Spectrographic Chart of Iron. Set of 18 cards, each 20 inches in length, prepared by direct printing from spectrograms made on a 10-meter focal length, 30,000-line grating is especially valuable for workers using higher orders of grating instruments since it charts three overlapping orders. Department of Physics, Massachusetts Institute of Technology, Cambridge, Mass.

A41 Herzberg, G. Atomic Spectra and Atomic Structure. Prentice-Hall, New York, 1937.

A42 Hilger, A. Spectrogram of Iron. A set of mounted photographic copies of a prism dispersion iron spectrogram with the wavelength positions of the lines indicated. Eight cards, 8 by 14 inches. Adam Hilger, Ltd., London, 1937.

A43 Hilger, A. Spectrogram of Copper. An enlarged spectrogram of copper from 2043 to 5782 A. Three cards, 6 by 14 inches. Adam Hilger, Ltd., London.

A44 Hilger, A. Spectrogram of Neon. Enlarged spectrogram on a card, 5 by 8 inches, showing 20 lines from 5850 to 7032 A. Adam Hilger, Ltd., London.

A45 Hilger, A. Spectrogram of Helium. Enlarged spectrogram on a card 4 by 12 inches, showing 19 lines between 3610 and 7282 A. Adam Hilger, Ltd., London.

A46 Hilger, A. Spectrogram of R. U. Powder. A set of seven enlargement photographs of the spectrogram of a sample of R. U. (raies ultimes) powder with the identified principal lines of 50 elements (prism dispersion). Adam Hilger, Ltd., London.

Hodgman, D. C. (Editor). Handbook of Chemistry and Physics. (See *A35*.)

A47 Hund, F. Linienspektren und periodisches System der Elemente. Springer, Berlin, 1928.

A48 International Critical Tables, Vols. V and VII. McGraw-Hill, 1929. Tables of Emission and Absorption Spectra Data. (See Brode, Chemical Spectroscopy, Chapters IV and IX.)

A49 Jenkins, F. A., and White, H. E. Fundamentals of Physical Optics. McGraw-Hill Book Co., New York, 1937.

A50 Jevons, W. Report on Band-Spectra of Diatomic Molecules. The Physical Society, London, 1932.

A51 Johnson, R. C. Spectra. E. P. Dutton and Co., New York, 1928.

A52 Kayser, H., and Kayser and Konen, H. Handbuch der Spektroscopie, S. Hirzel, Leipzig, 1901–34. Later volumes include: H. Kayser, Vol. 5, 1910, 45 elements A to N; H. Kayser, Vol. 6, 1912, 41 elements Na to Zr; H. Kayser and H. Konen, Vol. 7, 1934, 49 elements A to Nb; H. Kayser and H. Konen, Vol. 8, 1932, 19 elements Ag to Cu.

A53 Kayser, H. Emission Spectra of Elementary Substances. International Critical Tables, Vol. V, p. 276. (See *A48*.)

A54 Kayser, H. Tabelle der Schwingungszahlen. Hirzel, Leipzig, 1925.

A55 Kayser, H. Tabelle der Hauptlinien der Linienspektra aller Elemente (Table of Principal Lines in the Spectra of All the Elements). J. Springer, Berlin, 1926.

A56 Kayser, H., and Ritschl, R. Tabelle der Hauptlinien der Linienspektra aller Elemente, 2nd Edition, J. Springer, Berlin, 1939.

A57 Konen, H. Arc, Spark and Flame Sourçes. Handbuch der Physik, Vol. XIX, pp. 259–286, 325–330. (See *A37.*)

A58 Konen, H. Determination of Wavelength. Handbuch der Physik, Vol. XIX, pp. 777–801. (See *A37.*)

A59 Kronig, R. de L. Band Spectra and Molecular Structure. Macmillan Co., New York, 1930.

A60 Kronig, R. de L. The Optical Basis of the Theory of Valency. Macmillan Co., New York, 1935.

A61 Kuhn, H. Atomspektren. Hand- und Jahrbuch der chemischen Physik, Vol. 9, I. (See *A38.*)

A62 Landolt-Bornstein. Physikalische-chemische Tabellen. Edited by W. A. Roth and K. Scheel. 5th Edition, 1923, and three supplementary editions covering the literature to 1934. Julius Springer, Berlin.

Lange, N. A. (Editor). Handbook of Chemistry. (See *A36.*)

A63 Lewis, S. Judd. Spectroscopy in Science and Industry. Blackie and Son, Ltd., London, 1933.

A64 Ley, H. Spectrophotometry. Handbuch der Physik, XIX, pp. 613–666. (See *A37.*)

A65 Löwe, F. Analysis by Emission and Absorption Spectra. Handbuch der Physik, XXI, pp. 652–677. (See *A37.*)

A66 Löwe, F. Atlas der letzten Linien der wichtigsten Elemente. T. Steinkopff, Dresden and Leipzig, 1928.

A67 Löwe, F. Optische Messungen des Chemikers und des Mediziners. T. Steinkopff, Dresden and Leipzig, 1925. (See *B52.*)

A68 Lundegårdh, H. Die quantitative Spektralanalyse der Elemente. G. Fischer, Jena, Part I, 1929; Part II, 1934.

A69 Lyman, T. Spectroscopy in the Extreme Ultraviolet. 2nd Edition, Longmans, Green and Co., New York, 1928.

A70 Martin, E. J. U. S. Patent 2,043,053, 1936.

A71 Mecke, R., and Finkelburg, W. Band Spectra in Visible and Ultraviolet. Hand- und Jahrbuch der chemischen Physik, Vol. IX, Part 2. (See *A38.*)

A72 Mecke, R. Band Spectra. Handbuch der Physik, Vol. XXI, pp. 493–573. (See *A37.*)

A73 Meggers, W. F. Persistent Lines and Raies Ultimes of the Chemical Elements. International Critical Tables, Vol. V, p. 322. (See *A48.*)

M.I.T.-Harrison. 100,000 Line Tables. (See *A39.*)

A74 Negresco, T. Recherches expérimentales d'analyse spectrale quantitative sur les alliages métalliques. Les Presses Universitaires de France, Paris, 1927.

A75 Paschen, F., and Götze, R. Seriengesetze der Liniensprektren. Berlin, Julius Springer, 1922.

A76 Pauling, L., and Goudsmit, S. The Structure of Line Spectra. McGraw-Hill Book Co., New York, 1930.

A77 Pearse, R. W. B., and Gaydon, A. G. The Identification of Molecular Spectra. John Wiley and Sons, New York, 1941.

A78 Rawlings, F. I. G., and Taylor, A. M. Infrared Analysis of Molecular Structure. Cambridge University Press, London, 1929.

A79 Rollefson, G. K., and Burton, M. Photochemistry and the Mechanism of Chemical Reactions. Prentice-Hall, New York, 1939.

A80 Rowland, H. A. Solar Spectrum Tables and Charts. Revised (1928) by members of the staff of the Mount Wilson Observatory, Carnegie Institution of Washington.

A81 Scheibe, G. Chemische Spektralanalyse (in Physikalische Methoden der analytischen Chemie, Vol. I, edited by W. Böttger). Akad. Verlag., Leipzig, 1933.

A82 Scheibe, G., and Fromel, W. Molekülspektren von Lösungen und Flüssigkeiten. Hand- und Jahrbuch der chemischen Physik, Vol. IX, part 4. (See *A38*.)

A83 Scheibe, G., and Linstrom, C. F. Tabellen des Funken- und Bogenspektrums des Eisens zur Wellenlangenbestimmung be ider technischen Emissions-Spektralanalyse (from 3700 to 2300 A). R. Fuess, Berlin-Steglitz, 1933.

A84 Seith, W., and Ruthardt, K. Chemische Spektralanalyse. Julius Springer, Berlin, 1938.

A85 Smith, D. M. Metallurgical Analysis by the Spectrograph. The British Non-Ferrous Metals Research Association, London, 1933.

A86 Smith, D. M. Visual Lines for Spectrum Analysis. Adam Hilger, Ltd., London, 1928.

A87 Sommerfeld, A. Atomic Structure and Spectral Lines. D. P. Dutton, New York, 1919. Revised Edition, 1934.

A88 Stanley, F. Lines in the Arc Spectra of the Elements. Adam Hilger, Ltd., London, 1911.

A89 Strock, L. W. Spectrum Analysis with the Carbon Arc Cathode Layer. Adam Hilger, Ltd., London, 1936.

A90 Swings, P. La spectroscopie appliquée. Hermann et Cie., Paris, 1935.

A91 Tables annuelles de constantes et données numériques. Absorption spectra tables and data edited by V. Henri; emission spectra tables edited by L. Brunninghaus. Spectroscopic data published in separate volumes (I to XII), covering data from 1910 to 1934. McGraw-Hill, New York (American agents); Gauthier-Villars et Cie., Paris.

A92 Thompson, H. W. A Course in Chemical Spectroscopy. Oxford University Press, London, 1938.

A93 Twyman, F. (and contributors). The Practice of Spectrum Analysis with Hilger Instruments. 6th Edition. Adam Hilger, Ltd., London, 1933.

A94 Twyman, F., and Smith, D. M. Wavelength Tables for Spectrum Analysis. Adam Hilger, Ltd., London, 1931.

A95 Twyman, F. The Spectrochemical Analysis of Metals and Alloys. Chemical Publishing Co., New York, 1941.

A96 von Angerer, E. Apparate und Methode der Spektroskopie. Wien-Harms, Handbuch der Experimental Physik, Band 21. Akademische Verlagsgesellschaft. M. B. H. Leipzig, 1927.

A97 Watts, W. M. Index of Spectra. Wavelengths table including various appendices published during the period 1872–1931. T. M. F. Tamblyn-Watts, West-Cliff-on-Sea, Essex, England.

A98 Watts, W. M. An Introduction to the Study of Spectrum Analysis. Longmans Green and Co., London, 1904.

A99 Weigert, F. Optische Methoden der Chemie. Akad. Verlag., Leipzig, 1927.

A100 Wein-Harms. Handbuch der Experimentalphysik, Vol. 22, Zeeman-Effekt, Ergebnisse und Anwendungen der Spektroskopie, Raman-Effekt. Akad. Verlag., Leipzig, 1927–31.

A101 Wein-Harms. Handbuch der Experimentalphysik, Vol. 21, Anregung der Spektren, Apparate und Methoden der Spektroskopie, Starkeffekt. Akad. Verlag., Leipzig, 1927–31.

A102 Wein-Harms. Handbuch der Experimentalphysik, Supplement Vol. 1. Bandenspektren (by W. Weizel). Akad. Verlag., Leipzig, 1931.

A103 White, H. E. Introduction to Atomic Spectra. McGraw-Hill Book Co., New York, 1934.

A104 Wood, R. W. Physical Optics. Macmillan Co., New York, 1934.

B. ABSORPTION SPECTRA AND COLORIMETRY (BOOKS)

B1 Andant, A. Spectres de fluorescence. Grignard, Traité de chimie organique Vol. II. (See *B25*.)

B2 Becquerel, J., and Rossignol, J. Spectral Absorption of Light and Heat by Pure Inorganic Substances and Miscellaneous Materials (Nonmetals). International Critical Tables, Vol. V, p. 268. (See *A48*.)

B3 Beilsteins Handbuch der organischer Chemie, 4th Edition, Julius Springer, Berlin, 1935 to 1941.

B4 Bourguel, M., and Piaux, L. Applications de la spectrographie Raman à la chimie organique. Grignard, Traité de chimie organique, Vol. II. (See *B25*.)

B5 Branch, G. E. K., and Calvin, M. The Theory of Organic Chemistry. Prentice-Hall, New York, 1941.

B6 Brodhun, E. Photometry, Handbuch der Physik, Vol. XIX, pp. 469–538. (See *A37*.)

B7 Brode, W. R., and others. Recent Applications of Absorption Spectrophotometry. Adam Hilger, Ltd., 1932.

B8 Brode, W. R., and Leermakers, J. A. Constitution and Physical Properties of Organic Compounds. Gilman, Organic Chemistry, Vol. II. (See *B23*.)

B9 Carr, E. P., and Sherrill, M. L. Absorption Spectra Data—International Critical Tables, Vol. V. (See *A48*.)

B10 Cohen, J. B. Organic Chemistry for Advanced Students. Arnold, London, 1928.

B11 Color Index, edited by F. M. Rowe, Soc. of Dyers and Colourists, 1924.

B12 Danckwortt, P. W. Lumineszenz-Analyse im filtrierten ultravioletten Licht. Akad. Verlag., Leipzig, 1928.

B13 Darmois, E. Propriétés optiques des combinaisons organiques. Grignard, Traité de chimie organique, Vol. II. (See *B25*.)

B14 Dreisch, T. Absorption Spectra of Solid Compounds. Handbuch der Physik, Vol. XXI, pp. 164–189. (See *A37*.)

B15 Ellinger, F. Absorption Spectra data on Natural Products, Tabulae Biologicae, Vol. XII. W. Junk, Den Haag, 1937.

B16 Ellis, C., Wells, A. A., and Heyroth, F. F. The Chemical Action of Ultraviolet Rays. Reinhold Publishing Corp., New York. (Revised edition of original by C. Ellis and A. A. Wells. [1923].)

B17 Farbstofftabellen (Schultz), edited by L. Lehman, 7th Edition, Akad Verlag, Leipzig, 1930–40.

B18 Fabry, Ch. Introduction générale à la photométrie. Encyclopédie photométrique. Revue d'optique théorique et instrumentale, Paris, 1927.

B19 Formanek, J. Qualitative Spektralanalyse anorganischer Körper und Untersuchung und Nachweis organischer Farbstoffe auf spektroskopischen Wege. Julius Springer, Berlin, 1900–1926.

Forsythe, W. E., and others. Measurement of Radiant Energy. (See *A23*.)

B20 Frerichs, R. Photographic Spectrophotometry. Handbuch der Physik, Vol. XIX, pp. 688–704. (See *A37*.)

B21 Gibson, K. S., and others. Report of the Committee of Spectrophotometry of the Optical Society of America. From the Journal of the Optical Society of America, Vol. 10, pp. 169–241, 1925.

B22 Gibson, K. S. Spectral Filters. International Critical Tables, Vol. V, p. 271. (See *A48*.)

B23 Gilman, H. (Editor). Organic Chemistry, An Advanced Treatise. John Wiley and Sons, New York, 1938. (See Brode and Leermakers, Pauling, Johnson, Levene.)

B24 Gmelins Handbuch der anorganischer Chemie, 8th edition, Verlag Chemie, Leipzig, 1918 to 1941.

B25 Grignard, V. Traité de chimie organique, Vols. I and II (P. Baud, General Secretary). Masson et Cie., Paris 1936. (See Darmois, Ramart-Lucas, Lecomte, Andant, Bourguel, Martinet, and Piaux.)

B26 Hardy, A. C. Handbook of Colorimetry. The Technology Press, Cambridge, Mass., 1936.

B27 Heilmeyer, L. Medizinische Spektrophotometrie. Gustav Fischer, Jena, 1933.

B28 Henri, V. Structure des molécules. Hermann et Cie., Paris, 1925.

B29 Henri, V. Tables of Absorption Spectra Data. Tables annuelles de constantes et données numériques, and International Critical Tables. (See *A100* and *A48*.)

B30 Heinrich, F. Theories of Organic Chemistry. Translated from the fourth German edition by T. B. Johnson and Dorothy Hahn. John Wiley & Sons, New York, 1922.

B31 Herzberg, G. Molecular Spectra and Molecular Structure, Prentice-Hall, New York, 1939.

Heyroth, F. F. The Chemical Action of Ultraviolet Rays. (See *B16*.)

B32 Hibben, J. H. The Raman Effect and Its Chemical Applications. Reinhold Publishing Corp., New York, 1939.

B33 Hirschlaff, E. Fluorescence and Phosphorescence, Methuen and Co., London, 1938.

B34 Hoffman, W. S. Photelometric Clinical Chemistry, Wm. Morrow and Co., New York, 1941.

B35 Holmes, W. C. The Absorption Spectra of Dyes. International Critical Tables, Vol. VII, p. 173. (See *A48*.)

B36 Johnson, J. R. Modern Electronic Concepts of Valence. Gilman, Organic Chemistry, Vol. II. (See *B23*.)

B37 Jones, H. C., and others. The Absorption Spectra of Solutions. Carnegie Institution of Washington, 1905–10.

B38 Kohlrausch, K. W. F. Der Smekal-Raman-Effekt. Julius Springer, Berlin 1931.

B39 Kruss, G., and Kruss, H. Kolorimetrie und quantitative Spektralanalyse. Leopold Voss, Hamburg and Leipzig, 1909.

Landolt-Bornstein. Physikalische-chemische Tabellen (Absorption spectra data). (See *A62.*)

B40 Lasareff, P. P., and Nedopekin, P. M. Atlas des Spectres. Académie des Sciences, Leningrad, 1927.

B41 Lecomte, J. Le spectre infrarouge. Les Presses Universitaires de France, Paris, 1928.

B42 Lecomte, J. Spectres dans l'infra-rouge. Grignard, Traité de chimie organique, Vol. II. (See *B25.*)

B43 Levene, P. A., and Rothen, A. Rotary Dispersion. Gilman, Organic Chemistry, Vol. II. (See *B23.*)

B44 Lewis, S. Judd. Spectroscopy in Science and Industry. Blackie and Son, Ltd., London, 1933.

B45 Ley, H. Farbe und Konstitution bei organischen Verbindungen. S. Hirzel, Leipzig, 1911.

B46 Ley, H. Spectrophotometry. Handbuch der Physik, Vol. XIX, pp. 613–666. (See *A37.*)

B47 Ley, H. Absorption Spectra and Chemical Constitution. Handbuch der Physik, Vol. XXI, pp. 1–164. (See *A37.*)

B48 Ley, H. Fluorescence and Chemical Constitution. Handbuch der Physik, Vol. XXI, pp. 710–723. (See *A37.*)

B49 Lifschitz, I. Kurzer Abriss der Spektroskopie und Kolorimetrie. Johann Barth, Leipzig, 1927.

B50 Löwe, F. Colorimetry. Handbuch der Physik, Vol. XIX, pp. 667–687. (See *A37.*)

B51 Löwe, F. Analysis by Emission and Absorption Spectra. Handbuch der Physik, Vol. XXI, pp. 652–677. (See *A37.*)

B52 Löwe, F. Optische Messungen des Chemikers und des Mediziners, 3rd Edition, Theodor Steinkopff, Dresden and Leipzig, 1939.

B53 Lucas, H. J. Organic Chemistry. American Book Co., New York, 1935.

B54 Martinet, J. Couleur et constitution chimique. Grignard, Traité de chimie organique, Vol. II, Part II, p. 653. (See *B25.*)

B55 Martinet, J., and Alexander, P. Couleur et constitution chimique. G. Doin, Paris, 1924.

B56 Mees, C. E. K. Atlas of Absorption Spectra. Longmans, Green and Co., London, 1909.

B57 Miller, E. S. Quantitative Biological Spectroscopy, 1939, 2nd Edition (Absorption Spectra, Vol. I), 1940. Burgess Publishing Co., Minneapolis, Minn.

B58 Millson, H. E. The Phenomenon of Fluorescence, Calco Technical Bulletin 571, Calco Chemical Division American Cyanamid Co., Bound Brook, New Jersey, 1941.

B59 Morton, R. A. Radiation in Chemistry. Baillière, Tindall and Cox, London, 1928.

B60 Morton, R. A. Absorption Spectra of Vitamins and Hormones. Adam Hilger, London, 1935, 2nd Edition, 1942.

B61 Morton, R. A. Practical Aspects of Absorption Spectrophotometry. Institute of Chemistry, London, 1938.

B62 Neblette, C. B. Photography, Its Principles and Practice. 2nd Edition. D. Van Nostrand, New York, 1930.

B63 Pauling, L. The Significance of Resonance to the Nature of the Chemical Bond and the Structure of Molecules. Gilman, Organic Chemistry, Vol. II. (See *B23.*)

B64 Pauling, L. The Nature of the Chemical Bond. Cornell University Press, Ithaca, 1939.

B65 Pringsheim, P. Fluorescence and Raman Spectra. Handbuch der Physik, Vol. XXI, pp. 574–633. (See *A37.*)

B66 Radley, J. A., and Grant, J. Fluorescence Analysis in Ultraviolet Light, 3rd Edition, D. Van Nostrand, New York, 1939.

B67 Ramart-Lucas, P. Structure des molécules et spectres d'absorption, Spectres dans l'ultra-violet et spectres dans le visible. Grignard, Traité de chemie organique, Vol. II. (See *B25.*)

B68 Reinkober, O. Infrared Spectra. Hand- und Jahrbuch der chemischen Physik, Vol. IX, part 2, 1934. (See *A38.*)

B69 Scheibe, G. Chemische Spektralanalyse. (See *A81.*)

B70 Scheibe, G., and Fromel, W. Molekulspektren von Lösungen und Flüssigkeiten. Hand- und Jahrbuch der chemischen Physik, Vol. IX, part 4. (See *A38.*)

B71 Schumm, O. Die spektrochemische Analyse natürlicher organischer Farbstoffe. Gustav Fischer, Jena, 1927.

Tables annkelles de constantes et données numériques. Absorption spectra tables and data. See Henri (*B29* and *A100.*)

Schultz-Farbstofftabellen. (See *B17.*)

B72 Snell, F. D., and Snell, C. T. Colorimetric Methods of Analysis, 2 Vols. D. Van Nostrand, New York, 1937.

B73 Style, D. W. G. Photochemistry, E. P. Dutton and Co., New York, 1930.

B74 Teller, E. Infrared and Raman Spectra. Hand- und Jahrbuch der chemischen Physik, Vol. IX, Part 2. (See *A38.*)

B75 Twyman, F. The Practice of Absorption Spectrophotometry. Adam Hilger, Ltd., London, 1932.

B76 Twyman, F., and Allsopp, C. B. The Practice of Absorption Spectrophotometry (revised edition of *B75*). Adam Hilger, Ltd., London, 1934.

B77 Watson, R. E. Colour in Relation to Chemical Constitution. Longmans, Green and Co., London, 1918.

B78 Weigert, F. Optische Methoden der Chemie. Akad. Verlag., Leipzig, 1927.

B79 Wizinger, R. Organische Farbstoffe. F. Dümmlers, Berlin, 1933.

B80 Wood, R. W. Physical Optics, Macmillan Co., New York, 1934.

B81 Watson, H. B. Modern Theories of Organic Chemistry, Clarendon Press. Oxford, 1937.

C. RESEARCH PUBLICATIONS

C1 Albers, V. M., and Knorr, H. V. *J. Optical Soc. Am.*, **28,** 121 (1938); *J. Chem. Phys.*, **9,** 497 (1941).

C2 Allen, A. J. *J. Optical Soc. Am.*, **29,** 453 (1939).

C3 Anderson, L. C. *J. Am. Chem. Soc.*, **57,** 1673 (1935).

C4 Avery, W. A., and Ellis, C. F. *J. Chem. Phys.*, **10,** 10 (1942).

C5 Baird, W. S. *J. Optical Soc. Am.*, **31,** 179 (1941).

C6 Baird, W. S. *Proc. 6th Spectros. Conf.*, 80 (1939).

C7 Baly, E. C. C. *Rept. British Assn. Adv. Sci.*, 131 (1916); 244 (1920); 294 (1922); 341 (1928).

C8 Beckman, A. O., and Cary, H. H. *J. Optical Soc. Am.*, **31,** 682 (1941).

C9 Behaghel, O., and Schneider, E. *Ber.*, **69,** 88 (1936).

C10 Bell, F. K. *J. Am. Chem. Soc.*, **50,** 2940 (1928).

C11 Birge, R. T. *Rev. Mod. Phys.*, **13,** 233 (1941).

C12 Boyce, J. C. *Rev. Mod. Phys.*, **13,** 1 (1941).

C13 Breckpot, R., Creffier, J., and Perlinghi, O. *Ann. Soc. Sci. Bruxelles*, **57,** 295 (1937).

C14 Breckpot, R. *Spectrochimica Acta*, **1,** 137 (1939).

C15 Brode, W. R. *J. Am. Chem. Soc.*, **46,** 581 (1924).

C16 Brode, W. R. *Ind. Eng. Chem.*, **18,** 708 (1926).

C17 Brode, W. R. *Proc. Roy. Soc.*, A **118,** 286 (1928).

C18 Brode, W. R. *J. Am. Chem. Soc.*, **51,** 1204 (1929).

C19 Brode, W. R. *J. Am. Chem. Soc.*, **48,** 1877 (1926).

C20 Brode, W. R. *J. Phys. Chem.*, **30,** 56 (1926).

C21 Brode, W. R. *J. Am. Chem. Soc.*, **48,** 1984 (1926).

C22 Brode, W. R. *Bur. Standards J. Research*, **2,** 501 (1929).

C23 Brode, W. R. *Ber.*, **61,** 1722 (1928).

C24 Brode, W. R. *J. Am. Chem. Soc.*, **55,** 939 (1933).

C25 Brode, W. R. *J. Am. Chem. Soc.*, **53,** 2457 (1931).

C26 Brode, W. R. *Proc. 5th Spec. Conf.*, 60 (1938).

C27 Brode, W. R. *Proc. 5th Spec. Conf.*, 88 (1938).

C28 Brode, W. R. *Proc. Am. Soc. Testing Materials*, **35,** II, 1 (1935).

C29 Brode, W. R. *J. Applied Phys.*, **10,** 751 (1939).

C30 Brode, W. R. *Proc. 6th Spectros. Conf.*, 128 (1939).

C31 Brode, W. R., and Adams, R. *J. Am. Chem. Soc.*, **46,** 2032 (1924).

C32 Brode, W. R., and Appleton, J. L. *Proc. 7th Spectros. Conf.*, 36 (1940).

C33 Brode, W. R., and Bournique, R. A. Diss. for M.S. degree, Ohio State Univ., 1938.

C34 Brode, W. R., and Brooks, R. E. *J. Am. Chem. Soc.*, **63,** 923 (1941).

C35 Brode, W. R., and Cheyney, L. E. *J. Org. Chem.*, **6,** 341 (1941).

C36 Brode, W. R., and Eberhart, D. R. *J. Org. Chem.*, **5,** 157 (1940).

C37 Brode, W. R., and Ernsberger, M. L. *J. Am. Chem. Soc.*, **56,** 1842 (1934).

C38 Brode, W. R., and Ernsberger, M. L. *J. Org. Chem.*, **6,** 331 (1941).

C39 Brode, W. R., and Funkhouser, J. A. *J. Am. Chem. Soc.*, **56,** 2172 (1934).

C40 Brode, W. R., and Griffith, M. E. *Proc. Am. Dyestuff Reporter*, **26,** 90 (1937); *Bull. Ohio Agr. Expt. Sta.*, **23,** 122 (1938).

C41 Brode, W. R., and Herdle, L. E. *J. Org. Chem.*, **6,** 713 (1941).

C42 Brode, W. R., and Hodge, E. S. *J. Optical Soc. Am.*, **31,** 158 (1941).

C43 Brode, W. R., and Jones, C. H. *J. Optical Soc. Am.*, **31,** 743 (1941).

C44 Brode, W. R., and Littman, J. B. *J. Am. Chem. Soc.*, **52,** 1655 (1930).

C45 Brode, W. R., and Magill, M. A. *J. Bio. Chem.*, **92,** 87 (1931); *Ohio J. Sci.*, **33,** 127 (1933).

C46 Brode, W. R., Menzel, D. H., Boyce, J. C., et al. *Harvard Annals*, **105,** 87 (1937).

C47 Brode, W. R., and Morton, R. A. *Proc. Roy. Soc.*, A **120,** 21 (1928).

C48 Brode, W. R., Mowry, D. T., and Brown, J. B. *J. Biol. Chem.*, **142,** 671 and 679 (1942).

C49 Brode, W. R., and Patterson, J. W. *J. Am. Chem. Soc.*, **63,** 3252 (1941).

C50 Brode, W. R., and Piper, J. D. *J. Am. Chem. Soc.*, **57**, 135 (1935); **63**, 1502 (1941).

C51 Brode, W. R., and Silverthorn, R. W. *Proc.* **6***th Spec. Conf.* (1939).

C52 Brode, W. R., and Steed, J. G. *Ind. and Eng. Chem., Anal. Ed.*, **6**, 157 (1934).

C53 Brode, W. R., and Tryon, S. Diss. for Ph.D. degree, Ohio State Univ., 1937.

C54 Brode, W. R., and Wander, I. W. *J. Optical Soc. Am.*, **31**, 402 (1941).

C55 Brooker, L. G. S., et al. *J. Am. Chem. Soc.*, **63**, 3192, 3214 (1941).

C56 Brooker, L. G. S., and Smith, L. A. *J. Am. Chem. Soc.*, **59**, 67 (1937).

C57 Bunsen, R. W., and Kirchoff, G. *Pogg. Ann.*, **113**, 337 (1861).

C58 Carr, E. P. *J. Chem. Phys.*, **4**, 763 (1936).

C59 Carr, E. P., and Stucklen, H. *Proc.* **7***th Spectros. Conf.*, 128 (1940).

C60 Castille, A. *Bull. Acad. Belg.*, **12**, 498 (1926).

C61 Cholak, J., and Story, R. V. *J. Optical Soc. Am.*, **31**, 730 (1941).

C62 Churchill, H. V., and Churchill, J. R. *J. Optical Soc., Am.* **31**, 611 (1941).

C63 Clar, E. *Ber.*, **69**, 1671 (1936).

C64 Coblentz, W. W., see *D7*.

C65 Condon, E. U. *Phys. Rev.*, **28**, 1182 (1926); **32**, 858 (1928).

C66 De Gramont, A. *Compt. rend.*, **159**, 6 (1914).

C67 De Gramont, A. *Compt. rend.*, **171**, 1106 (1920).

C68 De Lasslo, H. *Proc. Soc.*, **A 111**, 355 (1926).

C69 Dieke, G. H. *J. Applied Phys.*, **10**, 780 (1939).

C70 Dieke, G. H. *Proc.* **6***th Spectros. Conf.*, 71 (1939).

C71 Dietert, H. W. *J. Optical Society Am.*, **31**, 693 (1941).

C72 Dietert, H. W., and Schuch, J. *J. Optical Soc. Am.*, **31**, 54 (1941).

C73 Dimroth, K. *Ber.*, **70**, 1631 (1937).

C74 Duffendack, O. S., and Wolfe, F. H. U. S. Patent No. 1,979,964.

C75 Duffendack, O. S., and Wolfe, F. H. *Proc.* **5***th Spectros. Conf.*, 24 (1938).

C76 Duffendack, O. S., Wolfe, F. H., and Smith, H. L. *Ind. Eng. Chem., Anal. Ed.*, **5**, 226 (1933).

C77 Duffendack, O. S., Wiley, F. H., and Owens, J. S. *Ind. Eng. Chem., Anal. Ed.*, **7**, 40 (1935).

C78 Edlén, B. *Arch. Mat. Astron. Fysik*, **28B** 1 (1941).

C79 Ellis, J. W. *J. Chem. Phys.*, **5**, 399 (1937).

C80 Ells, V. R. *J. Optical Soc. Am.*, **31**, 534 (1941).

C81 Fisher, N. I., and Hamer, F. M. *Proc. Roy. Soc.*, **A 154**, 703 (1936).

C82 Folkers, K., Stiller, E. T., Keresztesy, J. C., Stevens, J. R., and others. *J. Am. Chem. Soc.*, **61**, 1237, 1242, 1245 (1939).

C83 Forrest, J. W. *Proc.* **6***th Spectros Conf.*, 88 (1939).

C84 Frehaefer, M. K., and Snow, C. *Bur. Standards Misc. Pub.*, **56** (1921).

C85 Gatterer, A. *Spectrochimica Acta*, **1**, 352 (1940).

C86 Gerandas, M., Varga, E., and Fodor, G. V. *Z. physik. Chem.*, **A 181**, 315 (1938).

C87 Gerlach, W., and Schweitzer, E. *Z. anal. Chem.*, **77**, 213 (1929).

C88 Gerlach, W. *Metallwirtschaft*, **7**, 1318 (1929).

C89 Gibbs, R. C. *Rev. Mod. Phys.*, **4**, 278 (1932).

C90 Gibson, K. S., McNicholas, H. J., etc. *Sci. Papers Bur. Standards*, No. **440** (1922).

C91 Gibson, K. S., and Tyndall, E. P. T. *Sci. Papers Bur. Standards*, No. **475** (1923); *Tech. Papers. Bur. Standards*, **148** (1920).

C92 Gouy, A. *Ann. chim. phys.*, (5) **8**, 101 (1879).

C93 Hagenbach, A., and Percy, R. *Helv. Chim. Acta.*, **5**, 454 (1922).

C94 Hamburger, L., and Holst, H. *Z. wiss. Phot.*, **17**, 265 (1918).

C95 Hansen, G. *Z. Physik*, **29**, 356 (1924).

C96 Hantzsch, A., and Robertson, P. W. *Ber.*, **43**, 109 (1910).

C97 Hardy, A. C. *J. Optical Soc. Am.*, **28**, 360 (1938).

C98 Harrison, G. R. *Proc. 6th Spectros. Conf.* (1939).

C99 Harrison, G. R., and Bentley, E. P. *J. Optical Soc. Am.*, **30**, 290 (1940).

C100 Harrison, G. R. *J. Applied Phys.*, **10**, 760 (1939).

C101 Hartley, W. N. *Chem. Soc. Trans.*, **47**, 747 (1885).

C102 Hartley, W. N. *Phil. Trans. London*, (*I*), **175**, 326 (1884).

C103 Hausser, K. W., Kuhn, R., Smakula, A., and Kreuchen, H. *Z. physik. Chem.*, **B 29**, 371 (1935); Hausser, K. W. *Z. tech. Physik*, **15**, 10 (1939).

C104 Hausser, K. W., Kuhn, R., and Seitz, G. *Z. physik. Chem.*, **B 29**, 371, 391 (1935).

C105 Hemmendinger, H. *J. Optical Soc. Am.*, **31**, 150 (1941).

C106 Henri, V. *Physik. Z.*, **14**, 516 (1913).

C107 Henri, V. "Structure des molécules," *Soc. chim. phys.*, 12 (1925).

C108 Henri, V., and Schou, S. A. *J. chim. phys.*, **25**, 665 (1928); *Z. Physik*, **49**, 774 (1928).

C109 Hess, T. M., Owens, J. S., and Reinhardt, L. G. *Proc. 7th Spectros. Conf.*, 29 (1940).

C110 Hildebrand, J. H., and Pitzer, K. S. *J. Am. Chem. Soc.*, **63**, 2472 (1941).

C111 Hogness, R. R., Zscheille, F. P., and Young, T. F. *J. Phys. Chem.*, **38**, 1 (1934).

C112 Jenkins, F. A., and Wooldridge, D. E. *Phys. Rev.*, **53**, 137 (1938).

C113 Kaiser, H. *Spectrochimica Acta*, **1**, 1 (1939).

C114 Kaiser, H. *Proc. 7th Spectros. Conf.*, 77 (1940).

C115 Kerr, W. A. *Proc. 7th Spectros. Conf.*, 68 (1940).

C116 Klemperer, R. Diss., Dresden, 1910.

C117 Klingstedt, F. W. *Compt. rend.*, **176**, 1550 (1923).

C118 Knorr, H. V., and Albers, V. M. *Rev. Sci. Instruments*, **8**, 183 (1937).

C119 Kruger, P. G., and Pattin, H. S. *Phys. Rev.*, **52**, 625 (1937).

C120 Kuhn, R., and Deutsch, A. *Ber.*, **65**, 43 (1932).

C121 Kuhn, R., and Hoffer, M. *Ber.*, **65**, 651 (1932).

C122 Leonard, A. G. G., and Whelan, P. *Proc. Roy. Soc. Dublin* (*N.S.*), **11**, 23 (1908).

C123 Lewis, G. N., and Calvin, M. *Chem. Rev.*, **25**, 273 (1939).

C124 Ley, H. *Z. physik. Chem.*, **94**, 405 (1920).

C125 Liddel, U., and Kasper, C. *Bur. of Standards J. Research*, **11**, 599 (1933).

C126 Lockyer, J. N. *Phil. Trans. Roy. Soc.*, **163**, 253 (1873).

C127 Loofbourow, J. R. *Rev. Mod. Phys.*, **12**, 267 (1940).

C127*a* Lowry, T. M., and Richards, E. M. *J. Chem. Soc.*, **125**, 2511 (1924).

C128 Machler, R. C. *Proc. 7th Spectros. Conf.*, 65 (1940).

C129 Malpica, J. T. M. *Gen. Elec. Rev.*, **43**, 288, 333, 384 (1940); **44**, 563 (1941)

C130 McMurry, H. L. *J. Chem. Phys.*, **9**, 241 (1941).

C131 McNicholas, H. J. *Bur. Standards J. Research*, **1**, 939, 793 (1928).

C132 Mees, C. E. K. Eastman Kodak Research Lab. (1938).

C133 Meggers, W. F. *Proc. Int. Astronomical Union* (*Stockholm*), 1938.

C134 Meggers, W. F. *J. Applied Phys.*, **10**, 734 (1939).

C135 MEGGERS, W. F. *Proc. 6th Spectros. Conf.*, 114 (1939).

C136 MEGGERS, W. F. *J. Optical Soc. Am.*, **31**, 44, 605 (1941).

C137 MEGGERS, W. F., KIESS, C. C., and STIMSON, F. S. *Bur. Standards Sci. Paper*, **444** (1922).

C138 MEGGERS, W. F., and SCRIBNER, B. F. *Bur. Standards J. Research.*, **13**, 625, 657 (1934); **14**, 629 (1935); **17**, 126 (1936).

C139 MELLON, M. G. *Proc. 7th Spectros. Conf.*, 101 (1940).

C140 MELLON, M. G. *J. Optical Soc. Am.*, **31**, 648 (1941).

C141 MENCZEL, S. *Z. physik. Chem.*, **125**, 161 (1927).

C142 MEYER, C. F., and LEVIN, A. A. *Phys. Rev.*, **34**, 44 (1929).

C143 MICHAELSON, J. L., and LIEBHAFSKY, H. A. *Gen. Elec. Rev.*, **39**, 445 (1936).

C144 MICHAELSON, J. L. *J. Optical Soc. Am.*, **28**, 365 (1938).

C144*a* MILLER, E. S. *Plant Phys.*, **12**, 667 (1937).

C145 MORTON, R. A., and RIDING, R. W. *Proc. Roy. Soc.*, **A 113**, 711, 717 (1927).

C146 MRGUDICH, J. N. *Iron Age*, August-September (1940).

C147 MULLER, F., and SCHOLTAN, W. *Spectrochimica Acta*, **1**, 437 (1940).

C148 MULLER, R. H. *Ind. Eng. Chem., Anal. Ed.*, **13**, 667 (1941).

C149 MULLER, W., and SIEVERTS, A. *Spectrochimica Acta*, **1**, 332 (1940).

C150 MULLIKEN, R. S. *J. Chem. Phys.*, **7**, 353, 570 (1939).

C151 MUNCH, R. H. *J. Am. Chem. Soc.*, **57**, 1863 (1935).

C152 NEGRESCO, T. *J. chim. phys.*, **25**, 142–363 (1928).

C153 O'BRIEN, B. *Phys. Rev.*, **37**, 471 (1931).

C154 ORNDORFF, W. R., GIBBS, R. C., SHAPIRO, C. V., and MCNULTY, S. A. *J. Am. Chem. Soc.*, **49**, 1541 (1927).

C155 ORNSTEIN, L. S., and BRINKMAN, H. *Physica*, **1**, 797 (1933).

C156 OWENS, J. S. *Proc. 5th Spectros. Conf.*, 17 (1938); *Metals & Alloys*, **9**, 15 (1938).

C157 PAULING, L. *J. Am. Chem. Soc.*, **53**, 3225 (1931).

C158 PAULING, L., and SHERMAN, J. *J. Chem. Physics*, **1**, 679 (1933).

C159 PESTEMER, M., and FLASCHKA, H. *Monatsh.*, **71**, 325 (1938). PESTEMER, M., and MAYER-PITSCH, E. *Monatsh.*, **70**, 106 (1937).

C160 PFEILSTICKER, K. *Spectrochimica Acta*, **1**, 424 (1940).

C160*a* PFUND, H. *Astrophys. J.*, **27**, 297 (1908).

C161 PHILLIPS, L. W., and PARKER, W. L. *Phys. Rev.*, **60**, 301 (1941).

C162 PIERCE, W. C., TORRES, O. R., and MARSHALL, W. W. *Ind. Eng. Chem. Anal. Ed.*, **11**, 191 (1939).

C162*a* PIERCE, W. C., amd NACHTRIEB, N. H. *Ind. Eng. Chem. Anal. Ed.*, **13**, 774 (1941).

C163 POLLOK, J. H. *Proc. Roy. Soc. Dublin (N.S.)*, **11**, 16 (1907).

C164 POLLOK, J. H., and LEONARD, A. G. G. *Proc. Roy. Soc. Dublin (N.S.)*, **11**, 23 (1908).

C165 PRANDTL, W., and SCHEINER, K. *Z. anorg. allgem. Chem.*, **220**, 107 (1934).

C166 RAMAN, C. V. *Trans. Faraday Soc.*, **25**, 781 (1929).

C167 RANDALL, H. M. *J. Applied Phys.*, **10**, 768 (1939).

C168 ROBERTSON, P. W., and BRADY, O. L. *J. Chem. Soc.*, **103**, 1480 (1913).

C169 ROBERTSON, R., and FOX, J. J. *Proc. Roy Soc.*, **A 120**, 128 (1928).

C170 ROHNER, F. *Helv. Chim. Acta*, **31**, 23 (1938).

C171 ROSSLER, G. *Ber.*, **59**, 2606 (1926).

C172 Sawyer, R. A. *J. Applied Phys.*, **10,** 741 (1939).

C173 Sawyer, R. A., and Vincent, H. B. *Proc. 6th Spectros. Conf.*, **54,** (1939).

C174 Sawyer, R. A., and Vincent, H. B. *J. Optical Soc. Am.*, **31,** 47 (1941).

C175 Schactschabel, K. *Ann. Physik* (4), **81,** 929 (1926).

C176 Scheibe, G. *Ber.*, **59,** 1321 (1926).

C177 Scheibe, G. *Z. angew. Chem.*, **42,** 1017 (1929).

C178 Scheibe, G., and Neuhausser, A. *Z. angew. Chem.*, **41,** 1218 (1928).

C179 Scheibe, G. *Ber.*, **58,** 586 (1925).

C180 Schuster, A. *Astrophys. J.*, **21,** 197 (1905).

C181 Sheard, C., and States, M. N. *J. Optical Soc. Am.*, **31,** 64 (1941).

C182 Sheppard, S. E., Lambert, R. H., and Walker, R. D. *J. Chem. Phys.*, **9,** 96 (1941).

C182*a* Shurcliff, W. A. *J. Optical Soc. Am.*, **32,** 229 (1942).

C183 Sklar, A. L. *J. Chem. Phys.*, **5,** 669 (1937); **6,** 645 (1938).

C184 Slavin, M. *Proc. 7th Spectros. Conf.*, **51,** (1940).

C185 Smakula, A., and Wassermann, A. *Z. physik. Chem.*, **A 155,** 353 (1931).

C186 Smith, D. M. *J. Inst. Metals*, **55,** 283 (1934); **56,** 257 (1935).

C187 Smith, N. D. *J. Optical Soc. Am.*, **28,** 40 (1938).

C188 Sponer, H., Nordheim, G., Sklar, A. L., and Teller, E. J. *Chem. Phys.*, **7,** 207 (1939); Sponer and Teller, E. J. *Rev. Mod Phys.*, **13,** 75 (1941).

C189 Staats, E. M. *J. Optical Soc. Am.*, **28,** 112 (1938).

C190 Strock, L. W. *Spectrochimica Acta*, **1,** 117 (1939).

C190*a* Strock, L. W. *Proc. 6th Spectros. Conf.*, 134 (1940).

C191 Struve, O. *J. Applied Phys.*, **10,** 800 (1939).

C192 Thiel, A. *Fortschr. Chem. Physik physik. Chem.*, **18,** 38 (1924).

C193 Tuck, W. B. *J. Chem. Soc.*, **91,** 450 (1907).

C194 Twyman, F., and Simeon, F. *Trans. Optical Soc. (London)*, **31,** 169 (1930).

C195 Twyman, F., and Hitchen, C. S. *Proc. Roy. Soc. (London)*, **A 133,** 72 (1931).

C196 Twyman, F., and Harvey, A. *Trans. Optical Soc. (London)*, **33,** 1 (1931).

C197 Twyman, F. *Trans. Optical Soc. (London)*, **33,** 9 (1931).

C198 Twyman, F., Spencer, L. J., and Harvey, A. *Trans. Optical Soc. (London)*, **33,** 37 (1931).

C199 Van Someren, E. H. S. *J. Inst. Metals*, **55,** 273 (1934).

C200 Vierordt, K. *Wied. Ann.*, **3,** 359 (1878).

C201 Vincent, H. B., and Sawyer, R. A. *Spectrochimica Acta*, **1,** 131 (1939).

C202 Vincent, H. B., and Sawyer, R. A. *J. Optical Soc. Am.*, **31,** 639 (1941).

C203 von Halban, H. *Trans. Faraday Soc.*, **21,** 62 (1926); *Z. physik. Chem.*, **112,** 321 (1924).

C204 Wilhelm, H. A. *Ind. and Eng. Chem., Anal. Ed.*, **9,** 170 (1937).

C205 Williams, R. R., Ruehle, A. E., *et al.* *J. Am. Chem. Soc.*, **59,** 526, 530, 1052 (1937).

C206 Woodward, R. B. *J. Amer. Chem. Soc.*, **64,** 73 (1942).

C207 Wright, T. A. *Proc. 6th Spectros. Conf.*, **47,** (1938).

C208 Wright, W. D. *Trans. Optical Soc. (London)*, **29,** 225 (1928).

C209 Wulf, O. R., Liddel, U., and Hendricks, S. B. *J. Am. Chem. Soc.*, **58,** 2287 (1936).

C210 Wulf, O. R., and Deming, L. S. *J. Chem. Phys.*, **6,** 702 (1938).

C211 Zscheile, F. P. *J. Phys. Chem.*, **38,** 95 (1934).

C212 Zumwalt, L. R., and Badger, R. M. *J. Chem. Phys.*, **6,** 711 (1938).

D. ABSTRACT PUBLICATIONS AND GENERAL ARTICLES

Note: No attempt has been made to present a complete bibliography of research publications and journal articles. For such information one should consult the following sources:

D1 *Spectrochemical Abstracts* (1933–1937), Vol. I, by F. Twyman. Adam Hilger, Ltd., London, 1938. (A supplementary publication, Vol. II, has been compiled by E. H. S. van Someren covering 1938 [*D1a*].)

D2 *Bibliography of Literature on Spectrum Analysis* by D. M. Smith. British Non-Ferrous Metals Research Association, 1935.

D3 *Spectrochemical Analysis in 1938* by F. Twyman. Adam Hilger, Ltd., London, 1938.

D4 *Spectrographic Analysis in Great Britain* by A. C. Candler. Adam Hilger, Ltd., London, 1939.

D5 *Index to the Literature on Spectrochemical Analysis, 1920–1937*, by W. F. Meggers and B. F. Scribner. American Society of Testing Materials, 1939.

D6 *Chemical Abstracts* (yearly and cumulative indices). American Chemical Society.

The following publications should be available to workers in the field of spectrographic analysis:

D7 Research and Scientific Papers of the Bureau of Standards.

D8 Publications of Adam Hilger, Ltd., London.

D9 Proceedings, Reports, and Standard Specifications of Committee E-2 (Spectrographic Analysis) of the American Society of Testing Materials.

D10 Proceedings of the Conferences on Spectroscopy held at the Massachusetts Institute of Technology. Edited by G. R. Harrison, John Wiley & Sons, New York.

D11 Publications of the Bausch and Lomb Optical Company.

D12 Publications of the Eastman Kodak Company, including:
  (*a*) Photographic Plates for Use in Spectroscopy and Astronomy, 1940.
  (*b*) Kodak Reference Handbook, 1941.

D13 Publications of the Agfa Ansco Corporation.

D14 Photo-Lab-Index, edited by H. M. Lester, published by Morgan and Lester, New York, 1942.

D15 Publications of the Gaertner Scientific Company.

D16 Publications of the Spencer Lens Company.

D17 *Spectrochimica Acta.* A journal containing articles on spectrochemical problems. Edited by R. Breckpot, A. Gatterer, W. Gerlach, G. Scheibe, and F. Twyman, together with a large group of international contributors. Volume I started in 1939. Published by Julius Springer, Berlin.

D18 Annual Tables of Physical Constants and Numerical Data (A continuation of the International Critical Tables (*A48*) Edited by N. Thon. Chapters 1 and 2 cover data on atomic and molecular spectra, including both emission and absorption spectra data and special topics such as Raman spectra, infrared spectra, and fluorescent spectra. Includes data from 1925 with supplementary data sheets planned to keep the compilation up to date. Published under the auspices of the American Committee on Annual Tables, National Research Council. Publication office, Frick Chemical Laboratory, Princeton, N.J. (first sections published in 1942).

TABLES AND CHARTS

TABLE I

Strongest Lines of the First and Second Spectra of Chemical Elements (Meggers [C136])

Atomic Number	Element	FIRST SPECTRA (I)				SECOND SPECTRA (II)			
		Ionization Potential Volts	Low Term	High Term	Wave-length A	Ionization Potential Volts	Low Term	High Term	Wave-length A
1	H	13.529	$^2S_{0\frac12}$	$^2P_{1\frac12}$	1215.66				
2	He	24.465	$^1S_0$	$^1P_1^\circ$	584.33	54.144	$^2S_{0\frac12}$	$^2P^\circ_{1\frac12}$	303.78
3	Li	5.37	$^2S_{0\frac12}$	$^2P_{1\frac12}$	6707.85	75.258	$^1S_0$	$^1P^\circ_1$	199.26
4	Be	9.281	$^1S_0$	$^1P_1^\circ$	2348.61	18.119	$^2S_{0\frac12}$	$^2P^\circ_{1\frac12}$	3130.42
5	B	8.28	$^2P_{1\frac12}^\circ$	$^2S_{0\frac12}$	2497.73	24.998	$^1S_0$	$^1P^\circ_1$	1362.46
6	C	11.217	$^3P_2$	$^3P_2^\circ$	1657.01	24.260	$^2P^\circ_{1\frac12}$	$^2D_{2\frac12}$	1335.71
7	N	14.48	$^4S_{1\frac12}^\circ$	$^4P_{2\frac12}$	1134.98	29.443	$^3P_2$	$^3D^\circ_3$	1085.74
8	O	13.550	$^3P_2$	$^3S_1^\circ$	1302.19	34.941	$^4S^\circ_{1\frac12}$	$^4P_{2\frac12}$	834.47
9	F	18.6	$^2P_{1\frac12}^\circ$	$^2P_{1\frac12}$	954.8	34.81	$^3P_2$	$^3P^\circ_2$	606.81
10	Ne	21.47	$^1S_0$	$^1P_1^\circ$	735.89	40.91	$^2P^\circ_{1\frac12}$	$^2S_{0\frac12}$	460.73
11	Na	5.12	$^2S_{0\frac12}$	$^2P_{1\frac12}^\circ$	5889.95	47.065	$^1S_0$	$^1P^\circ_1$	372.07
12	Mg	7.61	$^1S_0$	$^1P_1^\circ$	2852.13	14.959	$^2S_{0\frac12}$	$^2P^\circ_{1\frac12}$	2795.53
13	Al	5.96	$^2P_{1\frac12}^\circ$	$^2S_{0\frac12}$	3961.53	18.733	$^1S_0$	$^1P^\circ_1$	1670.81
14	Si	8.12	$^3P_2$	$^3P_2^\circ$	2516.12	16.261	$^2P^\circ_{1\frac12}$	$^2D^\circ_{2\frac12}$	1817.0
15	P	11.1	$^4S_{1\frac12}^\circ$	$^4P_{2\frac12}$	1774.94	19.59	$^3P_2$	$^3D^\circ_3$	1542.32
16	S	10.3	$^3P_2$	$^3S_1^\circ$	1807.31	23.3	$^4S^\circ_{1\frac12}$	$^4P_{2\frac12}$	1259.53
17	Cl	12.96	$^2P_{1\frac12}^\circ$	$^2P_{1\frac12}$	1347.2	23.70	$^3P_2$	$^3P^\circ_2$	1071.05
18	A	15.69	$^1S_0$	$^1P_2^\circ$	1048.22	27.49	$^2P^\circ_{1\frac12}$	$^2S_{0\frac12}$	919.78
19	K	4.32	$^2S_{0\frac12}$	$^2P_{1\frac12}^\circ$	7664.91	31.7	$^1S_0$	$^1P^\circ_1$	600.77
20	Ca	6.09	$^1S_0$	$^1P_1^\circ$	4426.73	11.82	$^2S_{0\frac12}$	$^2P^\circ_{1\frac12}$	3933.67
21	Sc	6.7	$^4F_{4\frac12}$	$^4G_{5\frac12}^\circ$	5671.80	12.8	$^3D_3$	$^3F^\circ_4$	3613.84
22	Ti	6.81	$^5F_5$	$^5G_6^\circ$	4981.73	13.6	$^4F_{4\frac12}$	$^4G^\circ_{5\frac12}$	3349.41
23	V	6.76	$^6D_{4\frac12}$	$^6F_{5\frac12}^\circ$	4379.24	14.1?	$^5F_5$	$^5G^\circ_6$	3093.11
24	Cr	6.74	$^7S_3$	$^7P_4^\circ$	4254.35	16.6	$^6D_{4\frac12}$	$^6F^\circ_{5\frac12}$	2835.63
25	Mn	7.41	$^6S_{2\frac12}$	$^6P_{3\frac12}$	4030.76	15.56	$^7S_3$	$^7P^\circ_4$	2576.10
26	Fe	7.83	$^5F_5$	$^5G_6^\circ$	3581.20	16.16	$^6D_{4\frac12}$	$^6F^\circ_{5\frac12}$	2382.04
27	Co	8.5	$^4F_{4\frac12}$	$^4G_{5\frac12}^\circ$	3453.50	16.9	$^5F_5$	$^5G^\circ_6$	2286.14
28	Ni	7.606	$^3D_3$	$^3F_4^\circ$	3414.76	18.4	$^4F_{4\frac12}$	$^4G^\circ_{5\frac12}$	2216.47
29	Cu	7.68	$^2S_{0\frac12}$	$^2P_{1\frac12}^\circ$	3247.54	20.18	$^3D_3$	$^3F^\circ_4$	2135.98
30	Zn	9.36	$^1S_0$	$^1P_1^\circ$	2138.56	17.89	$^2S_{0\frac12}$	$^2P^\circ_{1\frac12}$	2025.51
31	Ga	5.97	$^2P_{1\frac12}^\circ$	$^2S_{0\frac12}$	4172.06	20.43	$^1S_0$	$^1P^\circ_1$	1414.44
32	Ge	8.09	$^3P_2$	$^3P_2^\circ$	2651.18	16.	$^2P^\circ_{1\frac12}$	$^2S_0$	1649.26
33	As		$^4S_{1\frac12}^\circ$	$^4P_{2\frac12}$	1890.5	20.1	$^3P_2$	$^3P^\circ_2$	1266.36
34	Se	9.5	$^3P_2$	$^3S_1^\circ$	1960.91	21.5	$^4S^\circ_{1\frac12}$	$^4P_{2\frac12}$	1192.29
35	Br	11.80	$^2P_{1\frac12}^\circ$	$^2P_{1\frac12}$	1488.4	19.1	$^3P_2$	$^3S^\circ_1$	1015.42
36	Kr	13.940	$^1S_0$	$^3P_1^\circ$	1235.82	24.47	$^2P^\circ_{1\frac12}$	$^2S_{0\frac12}$	917.43
37	Rb	4.159	$^2S_{0\frac12}$	$^2P_{1\frac12}^\circ$	7800.23	27.3	$^1S_0$	$^3P^\circ_1$	741.4
38	Sr	5.667	$^1S_0$	$^1P_1^\circ$	4607.33	10.98	$^2S_{0\frac12}$	$^2P^\circ_{1\frac12}$	4077.71
39	Y	6.5	$^4F_{4\frac12}$	$^4G_{5\frac12}^\circ$	5466.47	12.3	$^3D_3$	$^3F^\circ_4$	3710.29
40	Zr	6.92	$^5F_5$	$^5G_6^\circ$	4687.80	13.97	$^4F_{4\frac12}$	$^4G^\circ_{5\frac12}$	3391.98
41	Cb		$^6D_{4\frac12}$	$^6F_{5\frac12}^\circ$	4058.94		$^5F_5$	$^5G^\circ_6$	3094.18
42	Mo	7.35	$^7S_3$	$^7P_4^\circ$	3798.25		$^6D_{4\frac12}$	$^6F^\circ_{5\frac12}$	2816.15
43	Ma								
44	Ru		$^5F_5$	$^5G_6^\circ$	3498.94		$^6D_{4\frac12}$	$^6F^\circ_{5\frac12}$	2402.72
45	Rh	7.7	$^4F_{4\frac12}$	$^4G_{5\frac12}^\circ$	3434.89		$^5F_5$	$^5G^\circ_6$	2334.77
46	Pd	8.3	$^3D_3$	$^3F_4$	3404.58	19.8	$^4F_{4\frac12}$	$^4G^\circ_{5\frac12}$	2296.53
47	Ag	7.54	$^2S_{0\frac12}$	$^2P_{1\frac12}^\circ$	3280.68	21.9	$^3D_3$	$^3F^\circ_4$	2246.41

TABLE I (*Continued*)

STRONGEST LINES OF THE FIRST AND SECOND SPECTRA OF CHEMICAL ELEMENTS

Atomic Number	Element	FIRST SPECTRA (I)				SECOND SPECTRA (II)			
		Ionization Potential Volts	Low Term	High Term	Wave-length A	Ionization Potential Volts	Low Term	High Term	Wave-length A
48	Cd	8.96	${}^1S_0$	${}^1P_1^\circ$	2288.02	16.84	${}^2S_{0\frac{1}{2}}$	${}^2P^\circ_{1\frac{1}{2}}$	2144.38
49	In	5.76	${}^2P_{1\frac{1}{2}}^\circ$	${}^2S_{0\frac{1}{2}}$	4511.32	18.79	${}^1S_0$	${}^1P^\circ_1$	1586.4
50	Sn	7.297	${}^3P_2$	${}^3P_1^\circ$	3175.04	14.5	${}^2P^\circ_{0\frac{1}{2}}$	${}^4P_{1\frac{1}{2}}$	2152.22
51	Sb		${}^4S_{1\frac{1}{2}}^\circ$	${}^4P_{2\frac{1}{2}}$	2068.38	18.	${}^3P_2$	${}^3D^\circ_3$	1606.98
52	Te		${}^3P_2$	${}^3S_1^\circ$	2142.75				
53	I					19.4	${}^3P_2$	${}^5S^\circ_2$	1233.97
54	Xe	12.078	${}^1S_0$	${}^3P_1$	1469.62	21.1	${}^2P^\circ_{1\frac{1}{2}}$	${}^2S_{0\frac{1}{2}}$	1100.42
55	Cs	3.87	${}^3S_{0\frac{1}{2}}$	${}^2P_{1\frac{1}{2}}^\circ$	8521.10	23.4	${}^1S_0$	${}^3P^\circ_1$?	926.75
56	Ba	5.19	${}^1S_0$	${}^1P_1^\circ$	5535.55	9.96	${}^2S_{0\frac{1}{2}}$	${}^2P^\circ_{1\frac{1}{2}}$	4554.04
57	La	5.59	${}^4F_{4\frac{1}{2}}$	${}^4G_{5\frac{1}{2}}^\circ$	6249.93	11.38	${}^3D_3$	${}^3F^\circ_4$	3949.10
58	Ce					12.3?	${}^4H_{6\frac{1}{2}}$	${}^4I^\circ_{7\frac{1}{2}}$	4186.60
59	Pr						${}^5I^\circ_6$	${}^5K_7$	4179.42
60	Nd						${}^6I_{3\frac{1}{2}}$	${}^6K^\circ_{4\frac{1}{2}}$	4303.57
61									
62	Sm	5.6?	${}^7F_6$	${}^7G_3^\circ$	4296.75		${}^8F_{6\frac{1}{2}}$	${}^8G^\circ_{7\frac{1}{2}}$?	3568.27
63	Eu	5.64	${}^8S_{3\frac{1}{2}}^\circ$	${}^8P_{4\frac{1}{2}}$	4594.02	11.4	${}^9S_4$	${}^9P_3$	4205.05
64	Gd		${}^9D_6^\circ$	${}^9F_7$	4225.85				
65	Tb								
66	Dy								
67	Ho								
68	Er								
69	Tm						${}^3F^\circ_4$	${}^3F_4$?	3848.02
70	Yb	6.2	${}^1S_0$	${}^1P_1^\circ$	3987.99	12.05	${}^2S_{0\frac{1}{2}}$	${}^2P^\circ_{0\frac{1}{2}}$	3694.20
71	Lu	5	${}^2D_{2\frac{1}{2}}$	${}^2F_{3\frac{1}{2}}^\circ$			${}^1S_0$	${}^1P_1$	2615.43
72	Hf		${}^3F_4$	${}^3G_5^\circ$		14.8	${}^4F_{4\frac{1}{2}}$	${}^4G^\circ_{5\frac{1}{2}}$	2641.41
73	Ta		${}^4F_{4\frac{1}{2}}$	${}^4G_{5\frac{1}{2}}^\circ$					
74	W		${}^7S_3$	${}^7P_4^\circ$			${}^6D_{4\frac{1}{2}}$	${}^6F^\circ_{5\frac{1}{2}}$?	2204.49
75	Re	7.85	${}^6S_{2\frac{1}{2}}$	${}^6P_{3\frac{1}{2}}^\circ$	3460.47				
76	Os	8.7	${}^5D_4$	${}^5F_5$	2909.06				
77	Ir	9.2	${}^4F_{4\frac{1}{2}}$	${}^4G_{5\frac{1}{2}}^\circ$	2543.97				
78	Pt	8.9	${}^3D_3$	${}^3F_4^\circ$	2659.44	18.47	${}^4F_{4\frac{1}{2}}$	${}^4G^\circ_{5\frac{1}{2}}$	1777.09
79	Au	9.2	${}^2S_{0\frac{1}{2}}$	${}^2P_{1\frac{1}{2}}^\circ$	2427.95	20.0	${}^3D_3$	${}^3F^\circ_4$	1740.47
80	Hg	10.38	${}^1S_0$	${}^1P_1^\circ$	1849.68	18.672	${}^2S_{0\frac{1}{2}}$	${}^2P^\circ_{1\frac{1}{2}}$	1649.96
81	Tl	6.07	${}^2P_{1\frac{1}{2}}^\circ$	${}^2S_{0\frac{1}{2}}$	5350.46	20.33	${}^1S_0$	${}^3P^\circ_1$	1908.64
82	Pb	7.38	${}^3P_2$	${}^3P_1^\circ$	4057.82	14.96	${}^2P^\circ_{0\frac{1}{2}}$	${}^4P_{0\frac{1}{2}}$	1726.75
83	Bi		${}^4S_{1\frac{1}{2}}^\circ$	${}^4P_{0\frac{1}{2}}$	3067.72	16.6	${}^3P_2$	${}^3P^\circ_1$	1902.41
84	Po								
85									
86	Rn	10.689	${}^1S_0$	${}^3P_1^\circ$	1786.07				
87									
88	Ra	5.176	${}^1S_0$	${}^1P_1^\circ$	4825.91	10.10	${}^2S_{0\frac{1}{2}}$	${}^2P^\circ_{1\frac{1}{2}}$	3814.42

TABLE II

Persistent Lines by Wavelength (*Raies Ultimes* or *Letzten Linien*)

After de Gramont-Hartley-Twyman-Harrison-Meggers (*A93, C102, C66 A48, A35, A66, A39, C136*)

1800A to 8000A

Wavelength (angstroms)	Element	Wavelength (angstroms)	Element	Wavelength (angstroms)	Element	Wavelength (angstroms)	Element
′1849.68	Hg I	2307.86	Co II	2589.17	W II	2863.33	Sn I
54.7	Al III	11.47	Sb I	93.73	Mn II	71.51	Mo II
56.0	Al II	12.84	Cd II	98.06	Sb I	74.24	Ga I
58.1	Al II	′2344.77	Ru II	2605.69	Mn II	77.91	Sb I
62.5	Al II	35.27	Ba II	14.18	Pb	81.58	Si I
62.9	Al III	′48.61	Be I	′15.43	Lu II	90.99	Mo II
′90.5	As I	2349.84	As I	31.55	Al II	94.84	Lu
1906.64	Ti II	63.79	Co II	′41.41	Hf II	97.98	Bi I
1909.41	Bi II	69.67	As I	2650.78	Be I	98.26	Hf I
1936.6	As I	70.77	As I	′51.18	Ge I	98.71	As I
42.3	Hg II	78.62	Co II	51.58	Ge I	2904.41	Hf I
60.2	Se I	′82.04	Fe II	58.72	Pd II	′09.06	Os I
72.0	As I	83.25	Te I	′59.44	Pt I	09.12	Mo II
′2025.51	Zn II	85.76	Te I	′69.17	Al II	11.39	Lu
39.85	Se I	88.92	Co II	75.95	Au I	16.48	Hf I
61.70	Bi I	95.63	Fe II	78.76	Ru	18.32	Tl I
61.91	Zn II	97.09	W II	92.06	Ru	2924.79	Ir I
62.38	I	2404.88	Fe II	2709.63	Ge I	29.79	Pt I
62.79	Se I	10.52	Fe II	12.41	Ru	36.77	Ho
68.38	Sb I	13.31	Fe II	48.58	Cd II	38.30	Bi I
′2135.98	Cu II	′27.95	Au I	67.87	Tl I	40.77	Hf I
36.8	P I	37.80	Ag II	69.67	Te I	43.64	Ga I
′38.56	Zn I	56.53	As I	73.36	Hf II	45.67	Ru
′42.75	Te I	′78.57	C I	80.20	As I	65.55	Ru
′44.38	Cd II	88.92	Pd II	80.52	Bi I	76.59	Ru
2149.8	P I	96.78	B I	′95.53	Mg II	89.03	Bi I
′52.22	Sn II	′97.73	B I	2802.19	Au	97.97	Pt I
69.99	Pb I	98.78	Pd II	02.70	Mg II	3009.15	Sn I
75.89	Sb I	2502.00	Zn II	09.63	Bi I	34.12	Sn I
92.26	Cu II	2505.74	Pd II	′16.15	Mo II	39.07	Ge I
2203.50	Pb II	06.90	Si I	16.18	Al II	39.36	In I
′2204.49	W II	13.03	Hf II	20.21	Hf II	58.62	Os I
′2216.47	Ni II	′16.12	Si I	30.29	Pt I	64.71	Pt I
′46.41	Ag II	16.88	Hf II	33.07	Pb I	′67.72	Bi I
46.99	Cu II	19.82	Co II	′35.63	Cr II	71.59	Ba I
53.86	Ni II	28.52	Si I	2836.71	C II	72.88	Hf I
64.46	Ni II	28.53	Sb I	37.60	C II	82.16	Al I
65.02	Cd II	30.70	Te I	39.99	Sn I	92.71	Al I
70.21	Ni II	34.01	P I	43.25	Cr II	93.11	V II
76.58	Bi I	35.65	P I	48.23	Mo II	′94.18	Cb II
′86.16	Co II	36.52	Hg I	49.73	Ir I	3102.30	V II
′87.08	Ni II	′43.97	Ir I	49.84	Cr II	10.71	V II
′88.02	Cd I	53.28	P I	52.13	Mg I	18.38	V II
88.12	As I	54.93	P I	54.58	Pd II	25.28	V II
′96.53	Rd II	57.96	Zn II	55.68	Cr II	′3130.42	Be II
96.89	C III	73.09	Cd II	60.45	As I	30.79	Cb II
2304.23	Ba II	′76.10	Mn II	60.93	Cr II	31.07	Be II

The most persistent lines are indicated by a prime (′) mark.

TABLE II (*Continued*)

PERSISTENT LINES BY WAVELENGTH

Wavelength (angstroms)	Element	Wavelength (angstroms)	Element	Wavelength (angstroms)	Element	Wavelength (angstroms)	Element
3134.72	Hf II	3405.12	Co I	3642.78	Sc II	4012.39	Ce
58.87	Ca II	06.66	Ta	46.20	Gd	19.18	Th
63.40	Cb II	'14.77	Ni I	50.15	Hg I	20.40	Sc I
'75.04	Sn I	21.24	Pd I	53.50	Ti I	23.69	Sc I
79.33	Ca II	'34.89	Rh	54.83	Hg I	'30.76	Mn I
83.41	V II	36.74	Ru I	57.99	Rh I	32.98	Ga I
83.98	V II	37.02	Ir I	63.28	Hg I	33.07	Mn I
85.40	V II	38.23	Zr II	72.58	U	34.49	Mn I
94.98	Cb II	51.41	B II	83.47	Pb I	4040.76	Ce II
3215.56	W I	'53.51	Co I	92.36	Rh I	44.14	K I
'20.78	Ir I	60.47	Re I	92.65	Er	45.98	Dy
25.48	Cb II	62.21	Tm	'94.20	Yb	46.56	Hg I
29.75	Tl I	64.57	Sr II	'3710.29	Y II	47.20	K I
32.50	Sb I	65.80	Co I	19.94	Fe I	'57.82	Pb I
32.61	Li I	66.20	Cd I	37.13	Fe I	'58.94	Cb I
42.28	Pt II	72.48	Lu	45.56	Fe I	62.82	Pr
'47.54	Cu I	74.89	Sr II	45.90	Fe I	77.34	La II
56.09	In I	92.96	Ni I	48.17	Ho	'77.71	Sr II
58.56	In I	96.21	Zr II	48.26	Fe I	77.97	Dy
61.06	Cd I	'98.94	Ru I	61.33	Tm	79.73	Cb I
62.29	Os I	99.10	Er	61.92	Tm	93.2	Hf II
62.33	Sn I	3509.17	Tb	68.41	Gd	97.31	N III
67.50	Sb I	13.65	Ir I	74.33	Y II	'99.94	N I
67.94	Os I	15.05	Ni I	75.72	Tl I	4100.92	Cb I
3269.49	Ge I	16.94	Pd I	88.70	Y II	01.77	In I
73.96	Cu I	19.24	Tl I	'98.25	Mo I	03.37	N III
'80.68	Ag I	'19.60	Zr I	'3814.42	Ra II	09.98	N I
82.33	Zn I	3524.54	Ni I	29.35	Mg I	23.23	La II
89.37	Yb	29.81	Co I	32.31	Mg I	23.81	Cb I
90.59	Th	38.75	Th	38.26	Mg I	29.74	Eu II
3302.32	Na I	47.68	Zr I	48.02	Tm II	30.66	Ba II
02.59	Zn I	52.17	U	48.75	Tb	37.10	Cb I
02.99	Na I	54.43	Lu	64.11	Mo I	65.61	Ce II
'11.16	Ta	61.74	Tb	3874.18	Tb	67.97	Dy
18.84	Ta	68.27	Sm II	'88.65	He I	'72.06	Ga I
21.01	Be I	72.47	Zr II	91.02	Ho	77.32	Nd
21.09	Be I	'81.20		91.79	Ba II	'79.42	Pr
21.34	Be I	96.18	Ru I	3902.96	Mo I	'86.60	Ce II
23.09	Rh I	3600.73	Y II	05.53	Si I	89.52	Pr
45.02	Zn I	01.04	Th	06.32	Er	4201.85	Rb I
'49.03	Ti II	01.19	Zr I	07.48	Sc I	'05.05	Eu II
61.21	Ti II	09.55	Pd I	11.81	Sc I	11.72	Dy
72.80	Ti II	10.51	Cd I	'33.67	Ca II	15.52	Sr II
80.71	Sr II	13.79	W II	44.03	Al I	15.56	Rb I
82.90	Ag I	'13.84	Sc II	'49.10	La II	25.33	Pr
83.76	Ti II	30.74	Sc II	51.15	Nd	26.57	Ge I
'91.95	Zr II	33.12	Y II	'61.53	Al I	'26.73	Ca I
96.85	Rh I	34.69	Pd	68.47	Ca II	41.67	U
97.07	Lu	35.46	Ti I	87.99	Yb	'54.35	Cr I
3403.65	Cd I	39.58	Pb I	4000.45	Dy	67.02	C II
'04.58	Pd I	42.67	Ti I	'08.75	W I	67.27	C II

The most persistent lines are indicated by a prime (') mark.

TABLE II (*Continued*)

PERSISTENT LINES BY WAVELENGTH

Wavelength (angstroms)	Element	Wavelength (angstroms)	Element	Wavelength (angstroms)	Element	Wavelength (angstroms)	Element
4274.80	Cr I	4680.14	Zn I	5105.54	Cu I	5895.92	Na I
89.72	Cr I	82.28	Ra I	53.24	Cu I	′5930.65	La I
94.61	W I	4685.75	He II	61.19	I II	6103.64	Li I
96.75	Sm I	87.80	Zr I	67.34	Mg I	6231.76	Al II
4302.11	W I	94.13	S I	72.70	Mg I	43.36	Al II
′03.57	Nd	95.45	S I	83.62	Mg I	′49.93	La I
05.45	Sr II	96.25	S I	5204.52	Cr I	6362.35	Zn I
58.35	Hg I	4704.86	Br II	06.04	Cr I	6402.25	Ne I
′79.24	V I	10.07	Zr I	08.44	Cr I	38.47	Cd I
4384.72	V I	22.16	Zn I	09.07	Ag I	6562.79	H I
89.97	V I	22.55	Bi I	18.20	Cu I	′6707.84	Li I
90.86	Sm II	30.78	Se I	′5350.46	Ti I	6856.02	F I
4420.47	Os I	39.03	Se I	5400.56	Ne I	6902.46	F I
24.34	Sm II	39.48	Zr I	24.62	Ba I	65.43	A I
25.44	Ca I	42.25	Se I	55.15	La I	7055.42	Rn
34.32	Sm II	72.31	Zr I	60.74	Hg I	67.22	A I
34.96	Ca I	85.50	Br II	64.61	I II	7450.00	Rn
54.78	Ca I	94.54	Cl II	65.49	Ag I	7503.87	A I
55.9	Ca I	4810.06	Cl II	66.47	Y I	′7664.91	K I
56.6	Ca I	10.53	Zn I	5519.12	Ba I	98.98	K I
4500.98	Xe I	16.71	Br II	′35.55	Ba I	′7771.93	O I
′11.32	In I	19.46	Cl II	70.29	Kr I	74.14	O I
18.57	Lu	′25.91	Ra I	5608.80	Pb II	75.43	O I
24.74	Sn	32.07	Sr I	66.64	N II	′7800.22	Rb I
′54.04	Ba II	61.33	H I	71.80	Sc I	7947.60	Rb I
55.36	Cs I	72.49	Sr I	76.02	N II	8115.31	A I
93.18	Cs I	89.17	Re I	79.56	N II	8126.52	Li I
′94.02		4934.09	Ba II	82.66	Na I	83.27	Na I
4603.00	Li I	62.26	Sr I	88.22	Na I	94.81	Na I
′07.33	Sr I	′81.73	Ti I	5777.67	Ba I	′8521.10	Cs I
24.28	Xe I	91.17	Ti I	5852.49	Ne I	8943.50	Cs I
43.69	Y I	99.51	Ti I	70.92	Kr I	9212.91	S I
71.23	Xe I	5007.21	Ti I	75.62	He I	9228.11	S I
74.85	Y I	14.3	Ti I	′89.95	Na I	9237.49	S I

The most persistent lines are indicated by a prime (′) mark.

TABLE III

Persistent Lines by Elements

(*A93*, *C102*, *C66*, *A48*, *A35*, *A52*)

1600 A to 9000 A

Element	Wavelength (angstroms)	Element	Wavelength (angstroms)	Element	Wavelength (angstroms)	Element	Wavelength (angstroms)
A I	6965.43	Ba I	5777.67	Cb II	3225.48	Cu I	5218.20
	7067.22	Ba II	3891.79	Cd I	′2288.02	Cu II	′2135.98
	7503.87		4130.66		2312.84		2192.26
	8115.31		′4554.04		2573.09		2246.99
Ag I	′3280.68		4934.09		2748.58	Dy	4000.45
	3382.90	Be I	′2348.61		3261.06		4045.98
	5209.07		2650.78		3403.65		4077.97
	5465.49		3321.01		3466.20		4167.97
Ag II	2246.41		3321.09		3610.51		4211.72
	′2437.80		3321.34		6438.47	Er I	3499.10
Al I	3082.16	Be II	′3130.42	Cd II	′2144.38		3692.65
	3092.71		3131.07		2265.02		3906.32
	3944.03	Bi I	2061.70	Ce II	4012.39	Eu I	4129.74
	′3961.53		2276.58		4040.76		′4594.02
Al II	1671.0		2780.52		4165.61	Eu II	′4205.05
	1856.0		2809.63		′4186.60	F I	6856.02
	1858.1		2897.98	Cl II	4794.54		6902.46
	1862.5		2938.30		4810.06′	Fe I	′3581.20
	2631.55		2989.03		4819.46		3719.94
	2669.17		′3067.72	Co I	′3453.51		3737.13
	2816.18	Bi II	1909.41		3465.80		3745.56
	6231.76		4722.55		3529.81		3745.90
	6243.36	Br II	′4704.86	Co II	′2286.16		3748.26
Al III	1854.7		4785.50		2307.86	Fe II	′2382.04
	1862.9		4816.71		2363.79		2395.63
As I	′1890.5	C I	2296.89		2378.62		2404.88
	1936.6		′2478.57		2388.92		2410.52
	1972.0	C II	2836.71		2519.82		2413.31
	2288.12		2837.60		3405.12	Ga I	2874.24
	2349.84		4267.02	Cr I	′4254.35		2943.64
	2369.67		4267.27		4274.80		4032.98
	2370.77	Ca I	′4226.73		4289.72		′4172.06
	2456.53		4425.44		5204.52	Gd I	3646.20
	2780.20		4434.96		5206.04		3768.41
	2860.45		4454.78		5208.44	Ge I	′2651.18
	2898.71	Ca II	3158.87	Cr II	′2835.63		2651.58
Au I	′2427.95		3179.33		2843.25		2709.63
	2675.95		′3933.67		2849.84		3039.07
	2802.19		3968.47		2855.68		3269.49
B I	2496.78	Cb I	′4058.94		2860.93		4226.57
	′2497.73		4079.73	Cs I	4555.36	H I	4861.33
B II	3451.41		4100.92		4593.18		6562.79
Ba I	2304.23		4123.81		′8521.10	He I	′3888.65
	2335.27		4137.10		8943.50		5875.62
	3071.59	Cb II	′3094.18	Cu I	′3247.54	He II	1640.5
	5424.62		3130.79		3273.96		4685.75
	5519.12		3163.40		5105.54	Hf I	2898.26
	′5535.55		3194.98		5153.24		2904.41

The most persistent lines are indicated by a prime (′) mark.

TABLE III (*Continued*)

PERSISTENT LINES BY ELEMENTS

Element	Wavelength (angstroms)	Element	Wavelength (angstroms)	Element	Wavelength (angstroms)	Element	Wavelength (angstroms)
Hf I	2916.48	Li I	4603.00	Ne I	6402.25	Pt II	3064.71
	2940.77		6103.64	Ni I	′3414.77	Ra I	′4825.91
	3072.88		′6707.84		3492.96	Ra II	′3814.42
	4093.16	Lu I	4518.57		3515.05		4682.28
Hf II	2513.03	Lu II	′2615.43		3524.54	Rb I	4201.85
	2516.88		2894.84	Ni II	′2216.47		4215.56
	′2641.41		2911.39		2253.86		′7800.22
	2773.36		3397.07		2264.46		7947.60
	2820.22		3472.48		2270.21	Re	′3460.47
	3134.72		3554.43		2287.08		4889.17
Hg I	′1849.68	Mg I	′2852.13	O I	′7771.93	Rh I	3323.09
	2536.52		3829.35		7774.14		3396.85
	3650.15		3832.31		7775.43		′3434.89
	3654.83		3838.26	Os I	′2909.06		3657.99
	3663.28		5167.34		3058.62		3692.36
	4046.56		5172.70		3262.29	Rn	7055.42
	4358.35		5183.62		3267.94		7450.00
	5460.74	Mg II	′2795.53		4420.47	Ru I	3436.74
Hg II	1649.8		2802.70	P I	1774.8		′3498.94
	1942.3	Mn I	′4030.76		2534.01		3596.18
Ho I	3748.17		4033.07		2535.65	Ru II	′2334.77
	3891.02		4034.49		2553.28		2678.76
Ho II	2936.77	Mn II	′2576.10		2554.93		2692.06
I I	1782.9		2593.73	Pb I	2169.99		2712.41
	2062.38		2605.69		2614.18		2945.67
	5161.19	Mo I	′3798.25		2833.07		2965.55
	5464.61		3864.11		3639.58		2976.59
In I	3039.36		3902.96		3683.47	S I	1807.4
	3256.09	Mo II	′2816.15		′4057.82		1820.5
	3258.56		2848.23	Pb II	1682.4		4694.13
	4101.77		2871.51		′2203.50		4695.45
	′4511.32		2890.99		5608.80		4696.25
Ir I	′2543.97		2909.12	Pd I	′3404.58		9212.91
	2849.73	N I	′4099.94		3421.24		9228.11
	2924.79		4103.37		3516.94		9237.49
	3220.78		4109.98		3609.55	Sb I	′2068.38
	3437.02	N II	5666.64		3634.69		2175.89
	3513.65		5676.02	Pd II	′2296.53		2311.47
K I	4044.14		5679.56		2488.92		2528.53
	4047.20	N III	4097.31		2498.78		2598.06
	′7664.91	Na I	3302.32		2505.74		2877.91
	7698.98		3302.99		2658.72		3232.50
Kr I	5570.29		5682.66		2854.58		3267.50
	5870.92		5688.22	Pr I	4062.82	Sc I	3907.48
La I	5455.15		′5889.95	Pr II	′4179.42		3911.81
	5930.65		5895.92		4189.52		4020.40
	′6249.93	Nd I	3951.15		4225.33		4023.69
La II	′3949.10		4177.32	Pt I	′2659.44		′5671.80
	4077.34	Nd II	′4303.57		2830.29	Sc II	′3613.84
	4123.23	Ne I	5400.56		2929.79		3630.74
Li I	3222.61		5852.49		2997.97		3642.78

The most persistent lines are indicated by a prime (′) mark.

TABLE III (*Continued*)

PERSISTENT LINES BY ELEMENTS

Element	Wavelength (angstroms)	Element	Wavelength (angstroms)	Element	Wavelength (angstroms)	Element	Wavelength (angstroms)
Se I	′1960.2	Ta I	′3311.16	Tl II	1906.64	Y II	3242.28
	2039.85		3318.84	Tm I	3462.21		3600.73
	2062.79		3406.66		3761.33		3633.12
	4730.78	Tb I	3509.17		3761.92		′3710.29
	4739.03		3561.74	Tm II	′3848.02		3774.33
	4742.25		3848.75	U I	3552.17		3788.70
Si I	2506.90		3874.18		3672.58	Yb I	3289.37
	′2516.12	Te I	′2142.75		4241.67		′3987.99
	2528.52		2383.25	V I	3183.41	Yb II	′3694.20
	2881.58		2385.76		3183.98	Zn I	′2138.56
	3905.53		2530.70		3185.40		3282.33
Sm I	′4296.75		2769.67		′4379.24		3302.59
	4390.86	Th I	3538.75		4384.72		3345.02
	4424.34		3601.04		4389.97		4680.14
	4434.32		4019.18	V II	′3093.11		4722.16
Sm II	3568.27	Th II	3290.59		3102.30		4810.53
Sn I	2839.99	Ti I	3635.46		3110.71		6362.35
	2863.33		3642.67		3118.38	Zn II	′2025.51
	3009.15		3653.50		3125.28		2061.91
	3034.12		′4981.73	W I	′4008.75		2502.00
	′3175.04		4991.07		4294.61		2557.96
	3262.33		4999.51		4302.11	Zr I	′3519.60
	4524.74		5007.21	W II	′2204.49		3547.68
Sn II	′2152.22		5014.3		2397.09		3601.19
Sr I	4305.45	Ti II	′3349.03		2589.17		′4687.80
	′4607.33		3361.21		3215.56		4710.07
	4832.07		3372.80		3613.79		4739.48
	4872.49		3383.76	Xe I	4500.98		4772.31
	4962.26	Tl I	2767.87		4624.28		4815.6
Sr II	3380.71		2918.32		4671.23	Zr II	′3391.95
	3464.57		3229.75	Y I	4643.69		3438.23
	3474.89		3519.24		4674.85		3496.21
	′4077.71		3775.72		′5466.47		3572.47
	4215.52		′5350.46				

The most persistent lines are indicated by a prime (′) mark

TABLE IV *A*

ANALYSIS LINES FOR IMPORTANT ELEMENTS IN THE REGION OF 2400 TO 3300 A

(See Plates XXXVI to XL)

Strong, medium, and *weak* analysis lines are indicated by **bold face**, normal, an *italic* type. Important lines outside this spectral region are given in parentheses. semi-quantitative estimate of the elemental concentration can be made from th presence or absence of lines of different intensity values. (Hartley [*C122*]: Chola [*C61*]; Pierce [*C162*]; Gerlach [*A29*]).

Ag	2375, *2437*, *2448*, 2824, 2938, **3281**, (**3383**)
Al	2568, 2575, *3054*, *3064*, *3066*, **3093**, (**3962**)
As	**2350**, 2780, *2860*, *2899*
Au	**2428**, 2590, **2676**, 2748, 3123
B	**2497**, **2498**
Ba	*2634*, 3071, (**3501**)
Be	**2349**, 2651, *3019*, **3131**, 3321
Bi	*2697*, 2780, 2898, 2938, **3068**
C	**2479**
Ca	**2398**, 2721, *2995*, 3159, 3179, (**3934**)
Cd	**2288**, 2763, *2775*, 2837, **2981**, **3261**
Co	*2511*, 2521, 2649, *2731*, 2987, **3044**, **3072**, (**3405**, **3454**)
Cr	*2383*, 2409, **2781**, 2836, **2986**, **3015**, (**4254**)
Cu	2393, *2442*, 2618, *3108*, **3247**, **3274**
Fe	*2396*, 2483, 2599, *2749*, 2756, **3021**, 3101
Ga	*2874*, 2943, (**4033**, **4172**)
Ge	2651, *2754*, **3039**, **3269**
Hg	**2536**, 2752, 2967, *3021*
Ir	2544, *2850*, *2925*, 3133, **3221**
Mg	2780, *2782*, 2795, 2802, **2852**, *2915*, *3074*, 3097
Mn	**2576**, **2594**, **2606**, **2795**, *2914*, 2933, 2949, *3212*
Mo	**2816**, 2848, 2871, *2891*, **3132**, 3158
Na	*2680*, 2853, **3302**, (**5890**)
Ni	*2907*, 2943, **3002**, **3051**, 3081, *3129*
Os	2637, *2839*, **2909**, **3059**, **3302**
P	*2534*, 2553
Pb	**2393**, *2577*, 2614, *2650*, 2663, 2802, 2823, **2833**, 2873
Pt	2651, **2659**, 2702, **2830**, 2930, 2998, 3042, **3065**
Sb	*2474*, **2528**, **2598**, 2718, *2727*, 2770, **2878**
Si	*2435*, 2507, **2516**, 2519, **2882**, *2988*
Sn	*2422*, 2547, 2706, 2814, **2840**, **2863**, 3009, 3034, *3142*, **3175**
Ta	2647, 2653, 2675, 2714, 2892, 2902, (3311)
Tl	*2580*, 2609, 2709, *2721*, **3230**
Zn	(**2139**), 2608, 2771, **2801**, *3018*, 3035, *3075*, 3282

TABLE IV *B*

Analysis Lines for Important Elements in the Region of 3200 to 5100 A

(See Plates XXXVI to XL)

Strong, medium, and *weak* analysis lines are indicated by **bold face**, normal, and *italic* type. Important lines outside this spectral region are given in parentheses. A semi-quantitative estimate of the elemental concentration can be made from the presence or absence of lines of different intensity values. (Hartley [*C122*]; Cholak [*C61*]; Pierce [*C162*]; Gerlach [*A29*]).

Ag	**3281**, **3383**, *3933*, 3968, *3981*, 4055, 4210 **(5209)**
Al	**3944**, **3962**, (3082)
Ba	3501, *3910*, *4130*, **4554**, 4934
Be	**3321**
Ca	3350, *3487*, *3706*, **3934**, **3969**, **4227**
Cd	3261, 3404, **3466**, *3500*, **3611**, 4800, **5086**, (6438)
Co	**3405**, 3412, 3449, **3453**, **3502**, **3894**, **3995**, **4118**, **4121**
Cr	*3403*, 3408, 3605, *3928*, 3941, *3980*, 3991, 3992, *3994*, **4254**, **4275**, **4290**, 4496
Cs	*3876*, **4555**, 4593
Cu	**3247**, **3274**, 4022, *4104*, *4249*
Fe	**3581**, **3720**, **3735**, **3749**, 3753, 4045, 4063, **4271**
Ga	**4033**, **4172**
Hg	*3341*, 3650, 3663, **4358**
In	(3039), 3256, 3259, *4057*, **4101**, **4511**
Ir	**3513**, 3800, 4400
K	*3217*, 3447, **4044**, **4047**, (7665)
Li	**3233**, *3915*, 4273, 4603, **(6104)** **(6708)**
Mg	3332, 3336, **3829**, **3832**, **3838**
Mn	*3212*, 3531, **4031**, **4033**, **4034**, 4041, *4048*
Mo	**3194**, 3208, **3798**, **3864**, **3903**, 4062, 4070, *4128*
Na	3302, (5890)
Ni	*3310*, 3320, **3415**, **3446**, **3493**, **3524**, **3619**, 3674, *3994*
Pb	3640, 3683, *3740*, **4058**
Pd	**3243**, 3373, **3405**, **3421**, *3460*, 3609, **3634**
Rb	**4202**, 4215
Rh	3397, **3435**, 3503, 3528, 3658, *3692*, 4375
Ru	**3437**, **3499**, 3727, *3799*, **4554**
Sc	*3573*, 3614, 3631, 4024, 4247, 4314
Sn	**3262**, 3331. *3656*, **4525**
Sr	*3464*, **4078**, 4216, *4337*, **4607**
Th	*3291*, *3539*, *3601*, 3741, 3836, *4019*, 4069, 4391, 4919
Ti	3234, *3261*, **3349**, 3361, 3372, 3653, 3729
Tl	3230, **3519**, 3529, **3776**, (5351)
U	*3552*, *3670*, 3859, 4090, 4171, 4242
V	**3184**, 3202, 4112, 4379, 4385, *4390*, *4409*
W	(2944) **4009**, 4074, 4295, 4302
Zn	3282, **3303**, **3345**, *4298*, 4680, 4722, 4811
Zr	**3392**, 3438, 3496

TABLE V

Principal Lines by Wavelength

(*A55*, *A13*, *A81*, *A36*, *A48*, *A39*)

Wavelength values are given to unit angstrom values only; those elements with the same unit values are placed on the same line in the *order of their occurrence*, with a dash (—) to indicate the 0.5 angstrom position. If no dash appears, all the values are greater than 0.5.

To indicate intensity of lines the following notations are used:
Bold face type (Ba) indicates intensity above 300.
Normal type (Cs) indicates intensity 100 to 299 inclusive.
Italic type (*Sn*) indicates intensity 1 to 99 inclusive.
Intensity values are based on the Harrison-M.I.T. values. (*A39*).

The nonmetals and gases, He, Ne, A, Kr, O, N, Cl, Br, F, S, Se, H, and some of the rarer elements have been omitted from this table. (See Tables VII and VIII for spark spectra in air and principal lines by discharge spectra.)

For more complete tables see Kayser's "Hauptlinien" (*A55*) or Harrison's "100,000 line table" (*A39*).

Wavelength	Elements
2000	*Te I*—
01	**Te** *Ni* I
02	*Te* I—*As* I (R) *Te*
03	**As** I (R)—*Mn* (R)
06	*Ni* I
09	*As* I (R)
11	*Co*
12	*Au* I—
13	*As* I (R)—
14	*Ni* I (R)—*Co*
20	*Mo*—
21	*Bi* I—
22	*Co* II—
23	*P* I—*Bi*
24	*Cu* I (R)—
25	**Zn** II
27	*Co* II—
33	*P* I—
34	*Ni* I—
35	*Cu* II
37	*Cu* II—
38	*Mo*—
39	*Cr*—*Sb* **Te**
41	*Sn*—Bi
43	*Cu* II
45	*Os*—
47	*As* I
49	*Sb*—*Bi*
50	*Ni* I
54	*Sb*—*Cu* II
55	Cr II
56	Be I
57	*Bi* I
58	*Si* I
59	**Pb** (R) *Ni* I (R)
2061	*Ag* I Cr II—**Bi** I (R) Zn II
62	*Ni* I
63	*Ni* I *Sb*—
64	*Ni* I—*Bi*
65	*As* I *Cr* II—
68	**Sb** I—
69	*Ni* *Ni* I—*Ag* I
70	Te
73	*Bi*
74	*Te*
79	*Cu* I—
81	**Te** I—
82	*Si* I—*Ni* I
84	*Si* I—
85	*Ni* I—
87	*Pb*
88	*Pb* (R)—*V* *Hf* II *Ir* B I *Ni* I
89	*Ni* I (R)—B I
90	*Ni* I—
92	*Mn* (R) *Mn*—
93	*Mn* (R) *Co*—
95	*Ni* I—*Ni* I *Co*
96	Hf II—
97	*Co* *Mn*
98	*Sb*
2100	*Rh* *Fe* I
02	*Fe* I—
03	*Ca* II—
04	*Co*
05	*Cu* I—
06	*Mn* (R)—*Co*
07	*Fe* Te *Hf* II—Te
2108	*Fe* I—*Fe* I *Co*
09	*Re*—*Mn* (R)
10	Bi I (R)—
11	*Ni* II *Pb*
12	*Ca* II
13	*As* I—*Ag* II *Sn* (R)
15	*Pb* (R) *Fe* I—
16	*Yb*
17	*Os*
18	*Sb*
19	*Os*
21	*Ni* I—*Fe*
22	*Cu* II *Si* I
24	*Ni* Si I (R)—*Hf* II *Ni* I
25	*Fe*—*Ni* I
26	*Cu* II
27	*Sb*—*Fe* *Ni*
28	*Ni* I—
29	*Hf* II—*Ni* I
30	*Fe*—*Cu* I *Fe*
32	*Fe* I—
33	Bi I
34	Bi I (R) *Cu* II—
35	*Fe* *Cu* II
36	*P* I—
37	Os—*Co* I
38	*Cu* I **Zn** I (R) *Fe* I *Co* I
39	*Fe* I *Sb*
41	*Fe*—*Sb*
42	**Te** I
43	*Fe*
44	*As* I (R) *Cd* II *Fe*—
45	*Sb* *Fe* I—

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wavelength	Elements
2147	*Fe*—*Fe* *Ni* I
48	*Fe* *Sn* I (R)
49	*Cu* II *Fe*—
50	*Fe* I—*Ca* I
51	*Fe* I—*Fe* *Fe*
52	*Fe*—*Sn* *Ir* *Sr* II *Bi* (R)
53	*Fe* I—*Bi*
54	*P* I *Fe*—
55	*Fe* *Fe*
56	*Os* *Fe*—Bi (R)
57	*Fe* I
58	*Ir* *Ni* I (R) *Fe* I—*Os* *Sb*
59	*Sb*—*Pb* *Os* *Fe* I Te I *Fe* I *Os*
61	*Os* *Ni* I—*Fe* I Yb
62	*Fe* *Cr*—
63	*Co* I *Fe*—*Si* I *Fe* I
64	*Bi* *Fe*—
65	*Cu* I (R) **Pt** I (R)—*As* I (R) *Ni* II *Fe* *Sr* II (R)
66	Fe I (R) Te
67	*Os*
68	*Fe*
69	*Ni* II—*Cu* I *Fe* **Pb** I (R)
70	*Fe*
71	*Fe* I—*Cu* I
73	*Fe* I—*Ni* I
74	*Cu* II *Co* I (R)
75	*Be* I *Ni* II *Fe* I—*Pb* **Sb** I
76	*Au* I—*Bi* I *Fe* I
77	*Bi* I—
78	Fe I (R)—*Hf* II *Cu* I (R) *Co* *Fe*
79	*Sb*—
80	Pt—*Fe* I
81	*Co* II *Cu* I (R)
82	*Ni* I—*Co* I
83	*Fe*—*Fe*
84	*Ni* II
85	*Yb*
86	*Fe* I *Fe* (R)—*Ag* II *Fe* I
87	*Fe* I (R)—*Pb*
88	*Os*
89	*Fe*—*Bi* I *Cu* II
90	*Ni* I—*Fe*
91	*Ni* I *Fe* I *Mn*—Fe I (R)
2192	*Cu* II—*Fe*
93	*Fe*—
94	*Sn*(R)—
96	*Fe* I (R) *Co* I—
97	*Ni* I—*Ca* II
98	*Ir*
99	*Sn*—*Fe* *Cu* I (R) *Co* *Cu* I (R)
2200	*Fe* I (R)—*Co* *Ca* I *Fe* I
01	*Fe* I *Sb*—
02	*Bi*
03	*Bi*—*Pb* II
04	*Co* I
06	*Ni* II
07	*Fe* I *Te*—*Si* I
08	*Fe*—*Sb* *Ca* II Te I
09	*Sn* II
10	*Cu* II—*Fe* I *Sb* I
11	*Fe* I—*Si* I
13	*Mn*(R)
14	Re—*Cu* I (R)
15	*Cu* I
16	*Ni* II—*Si* I
18	*Si* I *Pb* *Cu* II—
20	*Ir* I—*Sb*
21	*Fe*
22	*Sb*—*Fe* *Ni* II
24	*Ni* II *Sb*
25	Cu I
26	*Re*—*Rh*
27	*Cu* I (R)
28	*Fe* I Bi I (R)—
29	*Fe*—
30	Bi I (R)
31	*Sn*
36	*Cu* I *Fe*—*Co* I
37	*Pb*—*Tl* I (R)
38	*Fe* I *Ru* *Cu* I—
39	*Cd*
40	*Fe*
41	*Ru*—*Fe*
42	*Pb* *Cu* II *Ir*
44	*Cu* I *Ni* I—*Ni* I
45	*Co* II—*Ba* II *Fe* I
46	Sn II (R) *Ag* II—*Pb* (R) *Cu* II
48	*Ag* II *Fe* I
49	*Fe* II *Bi* I—*Mo*
50	*Fe* II—*Fe* I *Fe* II
51	*Sn*—*Fe* I
53	*Fe* II—*Ru* Ni II *Pb*
2254	*Hf* II—*Ba* II
55	*Ru* Os *Fe* I
58	*Ni* I—
59	*Fe* I—*Fe* I Ni I
60	*Fe* II—*Cu* I *Fe* *Fe* II
62	*Sb* *Fe* II
63	*Cu* I *Al* I (R) *Fe* I—
64	*Rh* *Fe* I Ni II—*Co*
65	*Cd* II *Fe* I—
66	*Ni* I—*Hf* II *Fe* I
67	*Sn* *Fe* I *Cd*—
68	*Co* I—*Sn*(R)
69	*Al* I (R) *Fe* I *Al* I (R)—
70	*Sb* *Os* Ni II—*Fe* I
71	*As* I—*Fe* I
72	*Fe* I Ru—*Fe* I
74	*Fe* I—
75	*Fe* *Re*(R) *Ca* I—*Fe* I
76	*Fe* I *Cu* II—*Co*(R) Bi I (R)
77	*Fe* I Hf II—*Fe* I
78	*Ru*—
79	Os *Co* I—*Ni* Ru *Fe* I *Ag* II
80	*Fe* I—
81	*Bi*—*Fe*
82	*Sn* Os—*Fe* I
83	*Fe* I—*Fe* I *Os*
84	*Fe* I—*Hf* II *Cr* *Co* I
85	Zr *Ru*—
86	*Co* II—*Sn*
87	Ni II *Fe* I—*Fe* I *Ru*
88	**Cd** I (R) **As** I (R)—*Co* I *Sb*
89	*Fe* I—*Si* I *Ni* I (R)
90	*Fe* I—*Fe* I *Fe* I
91	*Zr* II *Fe* I *Ru* I—*Fe* I *Hf* II
92	**Pt** I—*Fe* I
93	*Sb*—*Cu* I *Fe*
94	*Zr* II *Fe* I—*Fe* II
95	*Co* I
96	*Co* I—*Fe* II *Co* I *Fe* I
97	*Ni* II—*Fe* I (R)
98	*Fe* I *Fe* II *Co* I—*Fe* *Mn*
99	*Fe* I *Ru* *Fe* I—
2300	*Fe* I *Ru*—*Fe* *Ni* I (R)
01	*Fe*—*Fe* I
02	*Hg* I—*Ru*

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) =0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

Principal Lines by Wavelength

Wavelength	Elements	Wavelength	Elements	Wavelength	Elements
2303	*Si* I *Cu* I Zr *Fe*—*Fe* I	2354	*Cu Fe* II *Bi*—Sn(R) *Fe* II	2400	*Co* I *Co* I Bi I (R)
04	Ir I *Ba* II (R)—*Fe* I *Mn*	57	*Ru Ag* II	01	*Co*—*Co* I *Ni* I (R Pt I *Pb*
05	*Co* I—	58	*Co* I—*Cu Ni* I	02	*Co* I (R)—*Co* I *Fe* I Ru
06	*Fe* I *Fe*—*Sb Cd In* I	59	*Fe* II—*Fe* II	03	**Pt** I Cu II *Co* I—*M* *Co*
07	*Co* II	60	*Fe* II *Sb*—	04	*Co* II *Fe* II—*Au* I *Fe* II
08	*Fe* I	61	*Cu*—	05	Re—*Re Mo*
09	Ag	62	*Fe* II *Ni* I *Cr* I—*Os*	06	*Co* I—*Ta Fe* II Cu I
10	*Mn Ni* I (R) Sb I (R)—	63	*Ir Cu* I—*Co* II *Fe*	07	*Fe* Co I—*Rh* I *Ru*
11	Sb I (R)—Co II	64	*Cr* I *Fe* II *Os*	08	*Fe* I *Sn*—Cr I (R) *Cr* I *Co* II
12	*Ni* I *Ag* II—*Zn*	65	*Co* I—*Cr* I	09	*Co* I—
13	*Fe* I	66	*Cr* I—*Fe* II *Cr* I	10	*Co Fe* II
14	*Co* II—*Co* II	67	Al I (R) *Os*—*Cr* I	11	*Fe* II *Ag* II—Co I (R) *Pb*
15	*Sb Tl* I (R)	68	*Rh Cr* I—*Fe* II	12	*Ni* I
16	*Ni* II—	69	*Os Fe* I—*As* I (R) *Co* I *Cu* II	13	*Mo Pt* I *Ag* II *Co* I *Fe* II—*Co*
17	*Ag* II *Ni* I (R) Sn(R)—*Fe*	70	*Ru Cr* I *Fe* II—*As* I (R)	14	*Co* I (R)—
18	*Fe*—	71	*Os Fe* I *Co*—	15	*Co* I (R) *Mo*—*W* Rh
19	*Cu* I	72	*Al* I *Mo*—*Fe* II Ir I *Co* I *Cr*	16	*Ni* II—*Mo* Ta
20	*Ni* I (R) *Ag* II *Fe* I—*Ru*	73	*Ba* I Al I (R) Al I (R) *Co*—*Sb Fe* II *Cr* I	17	*Co* **Fe** I—**Co** II **Fe** II
21	*Hf* II *Ni* I (R)—	74	*Hg* I *Fe* I	18	*Pt* I—
22	*Ru Hf* II—*Rh*	75	**Ag** *Ru*—*Ru*	19	*Co Ni* I (R)—
23	*Co* I *Hg* I—	76	*Ni* I *Au* I—	20	*Mo Mo Ru*
24	*Co* II—*Ni* I *Ag* II *V* I	77	*Os Fe*—*Os*	21	*Ni* I—Sn(R) *Re*
25	*Co* I *Ni* I (R) *Mo*	78	*Hg Al* I—*Co* II	22	*Sb*—*Co Ru Ru*
26	*Co* II *Co* II—	79	*Fe* II—Tl I (R) *Ni* I *Hg* I	23	*Fe* I *Ni* I—*Ni* I
27	*Fe* II—	80	*Co* I—*Sn Fe* II	24	*Ni* I *Fe* II—*Pt* II *Co* I (R) *Os*
28	*Bi*—	81	*As* I—*Ru*	25	*Li* I
29	*Sb Cd*—*Mg* II *Fe* I	82	*Fe* II (R)—*Rh*	26	*Sb*—
30	*Mo*—	83	*Fe* II *Fe* II **Te** I *Cr* I *Rh Co* II—*Sb*	27	Ta **Au** I (R)
31	*Fe* II *Ag* II—	84	*Mn Ni* I *Fe*—	28	Pt I *Sr* I *Fe* Pt I—
32	*Pb*—*Fe* II	85	*Fe* II—*Cr* I **Te** I	29	Pt I *Co* I Sn R—*Ru*
34	Sn(R)	86	*Rh Cr* I—*Ni* I *Cr* I *Ir*	30	*Fe* II *Mo Bi* I—
35	*Co* I *Ba* II (R)—	87	*Fe*—*Ni* I *Au* I *Ru*	31	*Fe Fe*—*Re Ir* I
36	*Os*	88	*Fe* II *Pb*	32	Re *Co* I (R *Fe* II—**Ta** (R) *Ru*
38	*Fe* II—	89	*Mo Cr* I—*In* I (R) *Fe* I	33	*Bi*—
39	*Fe*	91	*Ir Fe* II—	34	*Ni* I—*Ru Fe* II
40	*Mo V* I—*Os Ru*	92	*Cr Ru*—*Cr* I	35	*Co* Si I
42	*Ru Ru*	93	*Ru Hf* II—**Pb** *Zn Hf* II *Ru*	36	*Fe*—*Co*(R) *Ni Pt* I
43	**Hf** II *Fe* II—*Fe* II	94	*Ni* II	37	*As* I—*Ag* II *Ni* I
44	*As* I *Co* II—	95	*Sb Fe* II—*Fe* II *Cr* I	38	*Fe* I—*Si* I
45	*Fe Ni* II (R)—*Ni* I (R) *Hg* II *Bi*	96	*Ta Cr* I—*Ru* Os *Co*	39	*Co* I (R) *Fe* II—*Fe*
47	*Hf* II—*Ba*	98	Ca I (R)	40	**Pt** I *Fe*—
48	*Fe* II *Ru*—**Be** I (R) *Cu* II	99	*Cr* I *Fe* II *Hg* I—*Cr* I *Pb Hg* I	41	Cu I
49	*Ru*—As I (R)			42	*Fe*
50	*Be* I				
51	Hf II *Ru*—				
52	*Hg* I—*Mo Au* II *Co* I				

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wavelength	Elements
2443	*Si* I—Pb *Fe* I *Ta*
44	Rh I—*Fe* II *Ta*
45	*Sb Fe* II
46	Pb—Re
47	*Fe*—*Fe* I Pd I (R) *Ag* II
48	*Bi* I—
49	*Mg* II *Zn* I *Zr* II
50	*Co Fe Ni* I—**Pt** I Ni
52	*Si* I—
53	*Fe*—*Ni* I
54	*Ta Ta*—*Ru*
55	*Ru Fe*
56	*Co* I *Ru*—As I (R) *Ru*
57	*Fe*
58	*Ru Fe* II *Rh*
59	*Fe*—
60	*Co*—*Ta Fe Co* I *Mn*
61	*Mn Rh Fe* Re *Os*—*Fe* II *Re*
62	*Co Fe* I (R)—Fe I (R) *Ru*
63	*Zn* I—*Fe Fe* I
64	*Fe* II *Hg* I *Co* II—*Ru*
65	*Fe* I *Ta Ni* I *Fe*—
66	*Ni* I
67	**Pt**(R)—*Co* I *Fe* I
68	*In* I—*Fe*
69	*Mo Zn* I—
70	*Rh* I—*Fe* II *Ta Fe* I
71	Pt I *Rh* I—*Mo*
72	*Fe Ta Fe* I—**Fe** I (R) Mn **Fe** I
73	*Ni* II *Fe*—*Ag* II
74	*Ru Cr*—*Sb* Ta *Mo Fe*
75	Ir I Li I Ru—
76	*Fe Ru* Pb **Pd** I (R)—*Co* I *Fe* I *Ni* I *Ru*
78	*Ta Sb*—Hf II C I *Hg* I *Ru*
79	*Cr Fe* I—*Fe Zn* I Fe I (R)
80	*Tm Fe* II *Sb*—
81	*Ir* I—*Mo*
82	*Hg* I—*Ta Hg* I
83	**Fe** I (R) Rh I (R) Sn II—*Hg* I Re *Ru*
84	Fe I (R)—
85	*Mo Co* II—*Re Fe*
86	*Fe*—*Fe Re*
87	*Fe* I **Pt** I (R) *Re Fe* I Rh—
2488	Mn **Fe** I (R) *Ta*—*Os* I Ta *Fe*
89	*Ni* I Fe I (R) *Ru*
90	**Pt** I—Mn Fe I (R) *Ni* Rh
91	Fe I (R) Mn *Ni Au* I *Cr* I Zn I—*Fe*
92	Cu I (R) Rh I *Os*(R)—*Cr* I *As* I
93	*Fe* II *Fe* II *Zn* I—*Co Fe* I
94	*Ru Fe* I *Ru*—*Be* I *Be* I *Be* I
95	*Cr* I—*Ru* Sn *Fe* I
96	Cr I (R)—*Fe B* I *Fe*
97	*Mo Ru* **B** I *Fe* II *Mo*
98	*Ru*—**Pt** I *Ru* Fe I
99	*Bi Ru Cr* I
2500	*Fe*
01	Fe I (R) *Ni Rh*(R) *Ru*—*Fe* I *Re*
02	*Zn* II *Re*—Cr(R) Ir I
03	*Fe* II—*Fe Fe* II
04	*Pt* I Cr I (R) Ta—*Re*
05	*Fe Mo Fe*—*Fe* Pt
06	*Co* II—*Fe Ag* II **Si** I *V* I (R)
07	*Ru* Ta—*Co* I *Fe*
08	*Cr* I *Ru* I **Pt** I—*Mo Fe Cr* I Re I
09	*Ru Tm*—*Mo Rh* I
10	*Au* I—*Sb* **Fe** I (R) *Ni* II
11	*Fe* II *Cr*
12	*Fe*—Ta *Ru*
13	*Os Ru Fe Mo*—*Cr* I *Fe*
14	Pt I Si I—*Sb Mo*
15	Pt I *Ru*—*Pt* I Bi I *Rh* I Zn I
16	*Mo* Re Si I—*Fe* I *Cr* I
17	*Fe* II *Ru Mo*—*Ru Fe* I *Mo*
18	Fe I (R)—*Fe*
19	**Si** I—Cr I (R) V I (R) *Fe Ta Co* II
20	*Re* I *Sb*—*Fe*
21	*Co*(R) *In* I—Re(R) *Ru Fe* I
22	**Fe** I (R)
23	*Fe Sn*
2524	**Si** I *Ni* I (R) Fe I (R) Bi I—*Mo Co* II
25	*Fe Ru Fe* II *Cd*—
26	Ta V I *Fe* II Ta—*Ta Ru*
27	Fe I (R) *Mn*—
28	*Cr* I *Ni* I *Fe Cr* I V—**Si** I **Sb** I (R) *Ru Co* I (R) *Ni*
29	*Mn Fe* I (R) *Fe Pt* I—*Fe* II *Fe* I (R) *Mo*
30	*Zn* I *Co* I V I *Cr* I—*Fe*
31	*Sn*—
32	*Ni* I *Ta Si* I—*Fe Bi*
33	*Mn* Ir I *Ru* I—*Fe* II *Fe*
34	*P* I *Fe* II Ir I—*Hg* I Re
35	*Ag* II—*Ta* **Fe** I P I *Ni*
36	Ta Pt I **Hg** I (R) *Fe* II *Mo*
37	*Fe*
38	*Mo*—*Fe* II *Fe*
39	**Pt** I *Fe* I—*Zr* I
40	*Ni* I *Mo*—*Fe* II Fe I (R)
41	*Ru Cr* I—*Co* II
42	*Fe* Zr II *Zn* I—*Os Mo*
43	*Ru Mo Fe* II—**Fe** *Fe* Ir I
44	*Au* I *Ru* I *Co* I (R)—Fe *Cd* I
45	*Re*—*Rh Ni* II Fe I (R) *V* I
46	Ir I—Sn *Ta Fe*
47	*Ni* I—
48	*Fe Mo Co* I—
49	Ta *Pt* I—*Cr* I *Ru Fe* I (R)
50	*Fe* II—*Fe Zr* I Zr II *Mo*
51	Ta *Fe* Ta—Ta
52	*Re* Pt I—*Tl* I (R) *Fe V* I (R) *Fe Fe* I *Mo*
53	*Co* I (R) *Cr* I *Fe P* I *Ni* I—*Cd* I *Fe*
54	*Sb Ta Ta P* I
55	*Ta Fe* II *Fe* Rh I—*Fe*
56	*Fe Ru*—Re *Co* I *Fe*

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements
2557	*Cr* I—*Ta* *Zn* II
58	*Sn* *Re* *Fe*—*Ru*
59	Ta—*Ni*
60	In I (R) *Ru* *Fe* II—*Fe* I *Ta* *Cr* I
61	*Co* *Ni* I—*Mo* *Tm* *Fe* I
62	*Ta* *V* I *Fe* I—*Fe* II Li I
63	*Fe* *Ru* *Ta* *Fe* *Fe* II—*Mn* *Ta*
64	*Re*—*Fe* I *Ru*
65	*Ru*—
66	*Fe* II
67	*Mo* *Co* I (R) **Zr** II *Fe* Al(R)
68	*Zn* II—*Si* I *Ru* I *Fe* I **Zr** II
69	*Ta* *Sr* I (R)—*Fe* I *Fe* I Zn I
70	*Fe* *Fe* II *Ru*
71	**Zr** II (R)—Sn *Cr* I (R)
72	*Co* I *Mo*—Mn
73	*Mo* *Co*—*Co*(R) Ta *Re* Ta
74	*V* I *Sb* *Fe* II *Ta*—
75	Al(R) *Al* *Ta*—Mn *Fe* *Ag*
76	*Co* **Mn** II (R) *Hg* I—*Fe* I
77	*Si* I Pb *Ir* I *Ta*—*Cr* I *Ta* *Fe* II
78	*Ni* I—*Mo* *Co* I
79	*Fe* I—*Ta* Mn *Fe*
80	*Fe* I Tl I (R) Ta *Fe* *Cd* I—*Ru* *Co* I *Fe*
81	*Ru*—*Os*
82	*Bi* *Mo* *Co* II *Fe* Zn I Zn—*Fe* II
83	Fe
84	*Ta* *Ru* Mn—Fe I
85	*Co* I—*Ru* *Fe* II
86	Re *W*
87	*Fe*—*Fe*
89	*Ru*
90	Co I *Os*
91	*Ru* *Fe*—*Fe* II Cr I (R) *Mo*
92	*Ru* Ir I *Cd* I *Fe*—Cu I *Fe* *Re* Mn
93	Ta—*Fe* *Ta* *Fe* II Mn II (R) *Na* I (R) *Na* I (R)
2594	*Fe* *Fe* I *Sn*—*Ru*
95	*Re* I *Ta* *Mo*—Mn
96	Pt *Ta*—*Ba* I *Mo*
97	*Mo*—*Fe*
98	Sb I **Fe** II—*Ag* II *Fe*
99	**Fe** II Ta—**Fe** I *Fe* *Re* *Ti* I
2600	*Fe* *Ta* *Fe* *Mo*—*Bi* *Zn* I
01	*Ta* *Mo*—*Mo* *In* I (R)
02	*Cd* I—*Mo*
03	**Pt** I *Hg* I—*Fe* *Cr* I Re
04	*Fe* *Fe*
05	Ti I *Ru*—*Fe* I *Co* Mn II (R) *Ru*
06	*Co* I *Ag* II *Fe*—Fe I
07	*Tm* **Fe** II *Mo*—
08	*Ir* I—Zn I Fe Ta **Zn** I *Tl* I (R) *Ta*
09	*Ru* I *Fe*—
10	*Fe* I *Co* I
11	*Ru* *Fe* II *Ti* I *Ir* I Ta—**Fe** II
12	Ru *Sb*—*Ta* *Fe* I
13	*Os* *Mo* *Fe* *Fe* *Co*—*Pb*(R) **Fe** II
14	*Ru* *Co* I Ta Pb(R) *Fe* I—*Re* *Ru*
15	*Ru* *Mo* Lu *Fe* *Ta*—*Ta*
16	*Co* I *Fe*—*Mo*
17	**Fe** II *Ru* *Co* I
18	Fe I *Mn* **Cu** I—*Fe* I *Mn*
19	*Fe* II *Co* I *Mo*—Mn **Pt** I *Ru* *Mn*
20	*Re* *Re* *Fe* II—*Ru*
21	*Mo*—Fe II
22	*Co* I (R)—*Rh* I *Cr* Mn
23	*Re* *Fe* I—Fe I *Co* I *Ru*
24	*Mn* *Ta* *Fe* *Tm* *Fe*—*Mn*
25	*Hg* I—**Fe** II *Rh* I
26	*Ru* *Ru*—Mn
27	*Fe*—*Co* I *Ru* Bi I
28	**Pt** I *Pb* II **Fe** II—*Mo*
29	*Cd* I—*Fe* I *Mo* *Co* I
30	*Cu* I *Fe* II *Ru*—Mn
31	Fe II *Si* I Fe II—*Mo* *Ru* *Re* *Fe* II
32	*Ru* Fe I *Cd* I *Ti* I—*Ru* *Fe* I *Mg* I *Fe*
33	*Ru*—*Fe*
34	*Hg* I *Ba* II
2635	*Mo* **Fe** I *Ta* *Pd* II
36	*Fe* I—Re I *Mo* *Ru* *Ta* —Ta *Sn*
37	Os I—
38	*Mn* *Mo*—*Ru* *Mo* *Eu*
39	*Ru* **Pt** I *Cr*—*Cd* I Ir *Ru*
40	*Mo* *Ru*—*Mo*
41	Ti I Eu—Fe I
42	*Cr* *Fe* I—*Hg* I Re *Hg* Ru I
43	*Mo* *Ta*
44	Fe I *Os* Ti I *Mo*—
45	*Ta* *Fe* I—
46	*Ta* *Fe* Ta *Mo*—*Ta* **Pt** I
47	Re I *Mo* *Ba* II *Ru* Ta —Fe I *V* I
48	*Fe*—*Fe* *Mn*
49	*Mg* I Re *Mo*—*Co* I
50	*Co* I Pb *Ru* Be I—*Be* I *Be* I *Be* I *Be* I *Be* I **Pt** I
51	*Ge* I *Ru* I *Ta*—*Ge* I *Fe* I Ru *V* I Re I
52	Hg I Al I (R)—*Sb* Rh I
53	Ta *Mo*—*Hg* I *Yb*
54	*Re*—
55	*Mo* *Hg* I *Fe*—
56	*Fe*—Ta(R) *Fe* I
57	*Lu*
58	*Mo* Pt I *Fe*—*Os* *Fe*
59	*Fe* **Pt** I (R)—*Ru* I
60	Al I (R) *Cd* I *Fe* I *Ag* II—*Mo* *Mg* II *Mg* II
61	*Fe* I *Fe* Ta V I—*Ru* *Ru* *Ta* Ir I
62	*Fe* I *Fe*—
63	**Pb**—Re *Fe*
64	*Fe*—*Fe* II *Ru* I Ir I
65	*Mo*—*Ta*
66	*Fe* I—*Fe* II *Fe* I *Fe* I
67	*Fe* I *Ru*
68	*Ta* **Eu**—*Ir* I
69	*Fe*—*Ti* I *Ir* I
70	*Mo*—Zn I *Sb* *Re* *Fe*
71	*Cr* II *Ir* I *Re*
72	*V* *Mg* I—
73	*Fe* I Eu *Ru*—*Ru* *Co* I
74	*Fe* Re I—Pt
75	*Fe*—Ta Au I (R)
76	*Fe* *Ru*

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wavelength	Elements
2677	**Pt** I *Cr* II—Cd I *V*
78	*Fe* Eu—*Zr* II Ru
79	Fe I *V*—*Co Mo* Ti I
80	*Co Fe Na* I (R) *Ca* I *Na* I (R) *Fe* I—*Rh* I
81	*Fe Mn Ta*
82	*Fe*—*Mo Sb V*
83	*Mo*—*Re Fe*
84	*Fe Mo* **Zn** I Ta—*Fe* I
85	*Lu Co* I—Eu II
86	*Ru* I—*Fe*
87	*Cr* II *Mn*—V *Mo*
88	*Cr* I—Re *Mo*
89	Fe I *Fe*—*Os Fe* I *V Fe Ru*
90	*Fe* I *V Cr* I *Re*—*V*
91	*Cr* II Ta *Ge Fe*—
92	Eu *Sb Fe* I Ta—*Fe* I Mn *Fe* II
93	*Ru*—*Mg* I
94	Ir I *Co* I—Fe *Co* II *Ta*
95	*Fe Mg* I Mn—*Fe Fe Co* I *Fe*
96	*Mo Fe*—*Cr* I Bi *Bi* I (R) Ta *V* I
97	*Fe* I *Re* I—V I *Mo*
98	*Mg* I *Fe* Ta **Pt** I—*V* I *Hg* I
99	Fe I—*Hg* I *Os*
2700	*Zr* II *Ru* I—*Cr* I *Au* I V *Cu* II
01	*Eu* II *Ru*—Mn **Eu** *Fe Cr* I
02	*V* **Pt** I *Fe*—*Fe Ba* I *Ru* I
03	*Ta Cu* II *Cr* I—Rh I *Ru Fe* II Mn
04	*Ta*—*Fe* II
05	*Eu*—Rh *Mn* **Pt** I
06	*Fe* V—Sn(R) Fe I *Ta V Os*
07	Rh I *Fe*—*V Ru*
08	*Fe Co*
09	*Ru* **Tl** I(R)—*Rh* I *Fe*
10	Ta *Cr Ru* **In** I(R)—*Fe* I
11	*Fe*—Fe I *V*
12	*Cr* II *Ru* **Zn** I—*Cd* I
13	Pt *Ru* **Mn**—*Cu* II *Ru* In I(R)
2714	*Fe V* Rh I Fe II—*Os*(R) Ta *Fe* I
15	*Rh* I *Fe Mo Rh Fe* I Re I—*Cu V Ru Co* I
16	*Cr* I *Fe* II *Fe*—*Rh* I **Eu**
17	Ta *Mo Fe Ru*—Rh I *Fe*
18	*Ta Fe* I—Rh I *Cu* II *Sb*
19	**Fe** I (R) **Pt** I *Fe*—Ru *Co*
20	*Os* Rh *Mo Cu* I *Fe*—*Fe Rh* I Ta **Fe** I (R)
21	*Tm*—*Ru* I *Ca* I *Ag Ta Os*
22	*Fe* II *Co* I—VI *Zr* II *Ru* I *Re* I *Cr* II
23	**Fe** I *Cu* I
24	*Ru*—*Fe Fe* II *Fe* I
25	*Fe* I *Fe Ru*—*Fe* I
26	Fe **Mn** *Fe Zr* II—**Cr** I (R) *Ru*
27	*Ta*—Fe II Ta **Eu**
28	Fe—*V Fe Ru* Rh I *Fe* I
29	Eu II *Ru*—**Pt** I
30	*Fe Ru* I—Bi I *Fe* II *Ru* I *Fe* I
31	*Co V* I—*Ru* **Cr** I (R)
32	*Fe* II—*Os* Ta
33	*Ti* I *Mo*—*Mg* I **Fe** I *Ru Cd* I **Pt** I
34	*Fe* I *Fe* I *Ru* Pt I—*Fe* I *Fe*
35	Fe I—*Fe* I *Ru*
36	**Ta Cr** I (R)—*Mg* I Rh I *Fe Mo*
37	*Fe* I (R)—*Fe Fe*
38	*Fe* I Pt I—*Mn Ru*
39	*Ru* I *Cr*—Fe II *V Ti* I
40	*Cr* II Ta *Co* I—
41	*Cr Fe* Li I—
42	*Fe* I *Cr Fe* I *Fe* I—
43	*Fe* II—*Ru Fe Cr* II *Mo Ru*
44	Fe I—*Fe* I
45	*Fe Co* I *Cu* II *Mo*—*Fe Ru*
46	*Co* I *Ru* Fe II—Ta Ni I Fe II
47	Ta—*Fe* I Pt I *Ru*
2748	Cr I *Mo*—**Ta** *Cr* II
49	*Fe* II *Fe* II *Fe* II—*Ru* Ta
50	**Fe** I *Ru*—*Fe* I *Cr* II *Fe*
51	*Fe Mo*—*Cr* I *Fe Cr* II
52	*Co* I Ta *Mn Ru* **Ta** *Ru* Hg I (R) *Rh* I *Hg* **Cr** I (R)
53	*Fe Fe* II *V Ru*—*Fe* I Pt I **In** I (R)
54	*Fe* I *Mo Fe*—*Ru* I Pt I *Fe*
55	*Fe Cr*—**Fe** II
56	**Fe** I **Fe** I Zn I—*Fe* II *Cd* I
57	*Fe* II **Cr** I (R) Fe I—*Cr* II *Ru Fe*
58	*Re Ti* I Ta—*Co* I
59	*Mo Hg* I Fe I
60	*Fe Mn*
61	*Co* I *Os*—*Mo Ta* **Ta Cr** I (R) Fe I *Fe* II
62	Fe I *Ru*—*Cr* II *Fe Mo Fe* I
63	*Mo Cr* **Pd** II (R) Fe I *Ru*—*Mo Re* Cd I *Mo*
64	*Cd* Co I (R) *Fe* Cr I (R)—*Ru*
65	*Ru*—*V*
66	*Co Mo* **Cu** I *Co Re*—*Cr* II *Fe Mo Fe* I
67	*Mo*—*Fe* II *Ag* II **Fe** I *Cr* Rh I **Tl** I (R)
68	*Fe Rh Fe*—*Co Cu* I *Ru Fe* II
69	*Fe*—*Fe* I *Pt* I **Cr** I (R) Sb
70	*Ru Re* I—*Fe Ru Ta* **Zn** I **Zn** I
71	*Mo Ba* II *Mn*—Rh I **Pt** I *Fe*
72	**Fe** I *Fe*—*Fe Ru Co Fe*
73	*Fe Pt* I—*Fe Pt* I
74	*Mo Ru*—*Fe* I Ta *Co* I
75	*Cd* I Ta *Co* II *Ru Ta In* I *Mo*—*Co* I *Ru Cr* Ta *Ru* I
76	*Mn* Fe—*Mg*
77	*Cr Mo*
78	Rh I *Fe* Fe I *Mg*—*Mn Fe Co* I *Fe Ru*

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements
2779	Ta *Cr Fe* II *Mo*—Rh I *Sn Mg Mn*
80	*Mo As* I (R)—Bi I *Fe Fe* **Cr** I (R) *Fe*
81	*Fe Zn* I *Ta Mg*—**Fe** I
82	*Fe Ru* I—*Cu* I *Mn Mg*
83	Rh I—Re I *Fe* II
84	*Mo Fe Fe*—*Ru Ta* Mo
85	*Sn Tm Ba* I—*Ru* I *Co* I
86	*Fe Ag* II—*Fe*
87	**Ta**(R) *Ru Mo Sn Fe* I
88	Fe I Ta—
89	*Fe* I—*Fe*
90	*Co Mo Mn*—Ta *Mg* II
91	*Co* I Rh I *Re Fe*—Ta *Fe*
92	*Fe Co* I—*Ru Mo*
93	Pt I—*Fe* II
94	*Fe*—*Tm Fe* I Co(R) **Mn**(R)
95	*Fe* I—Mg II *Hg Fe* I *Cr Fe*
96	*Co* I **Ta**—Ta Rh I Os *Fe* I *Gd*
97	*Co* I *Tm*—Ta Fe I
98	*Mg* II Zr I **Mn**(R) Ta—Ni I Bi I
99	*Fe*—*Ag* II *Hg* I *Mn*
2800	*Fe Fe*—Ta **Zn** I
01	Zn I **Mn**(R) *Mo*—*Mo*
02	Pb(R) **Ta** *Ni*—Ti I *Cu* I Mg II Co *Ru* Eu
03	*Fe Fe* I **Pt** I *Hg* I *Ru*—*Fe* Co I
04	*Os Hg* I—**Fe** I *Fe*
05	*Ni* I—
06	*Fe Mn* **Ta**—Ta *Ru* Os Fe I
07	*Fe* I *Mo*—*Mo Re*
08	*Mn Ru* Fe *Mo*—*Fe*
09	*Mn*—Bi I *Gd Mo*
10	*Ru* I *Fe V*—*Ru* I Ta
11	*Co* I—*Co* I *Eu* II
12	*Fe*—*Mn*
13	Fe I *Mn*—*Sn Fe* II *Ru* Eu
14	*Os Ta*(R)—*Cr Re* Ta *Zr* I *Co* I
2815	Ta *Fe Mn* Ta—*Fe* I *Co* I (R) *Mo* Mo II
16	*Eu*—*Fe*
17	*Ru* I *Ta*—*Ta* Fe I *Mn*
18	*Pt Mo Ru* I—*Co* I *Mn Mn Ru* I
19	*Fe* Ta—Re I
20	*Hg Co* I—Eu *Fe* I *Cr*
21	*Fe* Ni I *Mn*—*Co* II
22	*Ru Sc* II *Cr*—*Mo*
23	Pb(R) Fe I—
24	**Cu** I *Ag*—*Ta*
25	*Co* I *Au*—Fe *Mo Fe* I
26	*Fe* I Tl I (R) *Ta*—*Fe Mo* Rh I *Cr Co* I
27	Ta *Rh* I—*Fe Fe* I Tm
28	*Ta* Eu *Mn* Fe
29	*Ru* I—*Mo*
30	**Pt** I (R)—*Mn Fe*
32	**Fe** I—
33	**Pb** I (R) *Ce Fe*—**Ta** *Co* I
34	Re(R) *Rh* I *Fe Mo Co* I—*Ni* I *Pt* I *Fe*
35	*Mo* Fe I—Cr II *Fe* I
36	*Fe*—*Ta*(R) *Rh* I Cd I *In* I
37	*Co* I (R) Zr I *Ce*—
38	Fe I—Os I (R) *Ni* I
39	*Mo* **Sn** I (R)
40	*Mn Cr Gd* Fe I—*Ru Fe*
41	*Ru Na* II
42	*Co* I—Ta *Fe*
43	*Fe* Cr II—Fe I **Fe** I
44	**Ta**(R) *Mo Os* Ta—*Zr* II Ta
45	Ta—Fe Fe I *Fe* I
46	*Cr*—*V Mg* I Ta *Fe* I
47	*Hg* I
48	Ta Mo II *Mg* I—Zr I **Ta** *Ru Fe* I
49	*Cr Mo*—*Cr* II
50	*Co* I Ta—*Sn Os Mo Co* I **Ta**
51	*Sb Cr*—*Fe Mg* I Fe I
52	*Ce* **Mg** I (R) Fe—Na I (R) *V* I *Fe* I
53	*Na* I (R) *Mo*—*Fe* I *Fe*
54	*Ru* I—
55	*V* I—*Cr* II
2856	*Rh* I—*Cr* II *Hg* I
57	*Ta Cr* II—*Fe V* I *Fe*
58	*Cu* I Ta—*Mn Cu* I Fe I *Cr* II
59	*Co* I *V* I
60	*Ru* I *As* I (R)—*Cr* II Os
61	*Ru* I—*Hf* II
62	*Cd* I Fe I—Eu *Cr* II *Co* I Rh I
63	**Sn** I (R) *Fe* I—*Bi* I *Mo* Fe I
64	*Mo Rh*—Ta *Mo*
65	*Cr* II—
66	*Hf*—Fe I *Ru* I *Mo Cr* II
67	*Cr Fe*—*Fe Cr* II *Fe* I
68	*Fe* Cd I *Fe* II—Ta *Fe* II
69	Tm **Fe** I—*Fe*
70	*Cr* II—*V* I (R)
71	Rh Ta—Mo II *Cr* I *Ru Re* I
72	Fe I *Os*—*Mn*
73	*Cr* Pb(R) Ta *Cr* II—*Fe* Ta *Rh Cr* II
74	Ta **Fe** I—*Fe Os Ru*
75	*Re* I *Fe* I *Cb*(R)—*Zr* I *Cr* II
76	*Fe Ta*(R) *Cr* II—
77	Fe I—Sb I *Cr* II
78	*Mo Cr*—*Rh* I
79	*V* I *Cr* I *Fe*—*Ta Co* Ta *Ru*
80	Ta—*Fe* I *Fe* II Cd I (R) *Cr* II
81	*Cr Cd* I (R)—**Si** I
82	*Co* I *Rh*—*Mn*
83	Cb *Re Au* I—*Fe*
85	*Fe*—
86	**Fe** I *Co* I—Ru *Mo* Cr I
87	*Fe*—*Mo* Re I *Fe*
88	*Pt* I—
89	*Rh* I *Cr* I (R)—*Rh* I *Fe Fe*
90	*Cr*—*Tm Mo* II
91	Ta *Yb Cr*—*Fe* **Ta** *Fe*
92	*Ta Co* Fe—*Mn Mo*
93	Cr I (R) *V* II—*Hg* I *Fe* I Eu **Pt** I *Fe* I
94	*Cr Mo*—Fe *Lu*

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A

TABLE V (*Continued*)

Principal Lines by Wavelength

Wave-length	Elements
2895	Fe I Ta *Co* I—
96	Re I—*Cr* I (R)
97	*Mo* **Pt** I **Bi** I (R)
98	*Hf* I Fe—*Mo As* I (R) *Fe*
99	Ta *Cr* I Fe—*Co* I *Rh* I
2900	*Lu* Ta—*Mn*
01	Ta Fe I—Fe
02	**Ta** *Mn* Re I—
03	*Mo Co*
04	**Ta** *Fe*—*Cr Na* II
05	*Ta Mo Fe Cr* I (R)— Re I *Ru* I Pt I
06	*Fe*—**Eu**
07	Rh I *Mn Ni* I— Fe I *Mn*
08	*V* II (R) *Fe* Ta
09	*Cr* I (R) **Os** I (R) *Mo* II—*Fe*
10	*Rh*—*Cr* I (R) *Fe*
11	*Cr* I Lu—*Mo*
12	Fe I **Pt** I *Os*—Rh I
13	*Ru*—**Pt** I Sn *Cr*(R)
14	*Ni* I Ta *Fe Ru Fe* I— Mn *V* I
15	Ta *Rh* I Ta—*Mg*
16	*Mo* Ru I *Hf* I—
17	*Ru*
18	*Fe* **Tl** I (R) *Fe*—*Fe*
19	*Fe* Pt I—*Co* I *Ru* Os *Fe*
20	Fe I *Fe*
21	Pt I—Tl I (R)
22	*Fe* I Pd I—*Fe*
23	*Fe Mo Fe*—*V* I (R) Fe
24	Rh I *V* II (R)—*V* II
25	Eu Ta *Fe Hg* I—Mn Ta *Fe Fe* L
26	Ta—Fe II *Tm*
27	Re—*Ru Fe Co* I Cb
28	*Fe* I—*Mn Mg* II· *Fe* I *Co* I
29	Fe I Rh *Fe Ag* II— *Co* I *Fe* I **Pt** I (R)
30	*Mn*—*Mo Re*
31	*Fe*—*Fe Sr* I *Rh* I *Fe*
32	**In** I **Ta**
33	*Mn*—Ta
34	*Mn Ag* II *Mo Fe* I *Cr*—

Wave-length	Elements
2935	*Mn Tm*
36	*Fe* II *Fe*—*Mg* II **Fe** I (R)
37	*Mo Hf* II **Fe** *Mn*
38	**Bi** I *Ta*—*Mg* I Ag II
39	*Fe* I Ta *Mn*—
40	Ta Ta *Ru* I *Mn Mn*— Fe *Hf* I
41	*Mn* **Fe** I—*Cb*
42	*Mg* I Ta *V* I (R)—*Fe*
43	*Re* I *Co* I—*Fe* *Ni* I (R) *Ru*
44	*Mo Fe* II—*V* II
45	*Tl* I Fe—*Ru Fe*
46	*Mo*—Ta *Ru* I
47	*Fe*—*Fe* II **Fe** I (R)
48	Ti I *Fe*—*Fe* I *Fe* I
49	Mn—*Ru* I *Fe*
50	**Fe**—Cb
51	*Na* II—*Fe* **Ta**
52	*Ru* I—Eu
53	**Fe**—*Fe* II **Fe** I (R)
54	Ru—Fe
55	*Ru Co*—
56	*Mn* Ti I—*Fe* I
57	*In* I **Fe** I—Ta *Co*
58	*Ru* I—
59	*Fe*—Fe Fe
60	Eu *Fe*—*Fe Fe*
61	**Cu** I *Cd* I—*Ru*
62	*V* I
63	*Lu* **Ta** *Ru*—*Mn Ru* I *Ta*
64	*Hf*
65	Re I *Ru* I **Fe** I—Ta *Ru* Re I *Fe Tm*
66	*Co* **Fe** I (R)
67	Hg—*Hg* I *Cr* I (R) *Mg* II
68	*Fe*—Rh I *Ru* I
69	*Fe* I Ta *Fe* I—Ta
70	**Fe** I *Si* I—*Fe* II Yb
71	*Cr* I (R)—*Mg* II *Fe*
72	Fe I—*Mo Mo*
73	**Fe** I (R) **Fe** I (R)— *Ru*
74	*Fe Na* II
75	Cr I (R)—Ta *Hf* II
76	Fe *Re* I—*Fe* I *Ru Ru*
77	*Ru*—*V* I Rh I
78	*Co* I *Fe Cu* I *Mo*—*Ru* Ta (R)

Wave-length	Elements
2979	*Fe* II—*Na* II *Ru*
80	Fe **Cd** I (R) *Cr* I (R) *Hf*
81	Cd I (R) **Fe** I *Tm*— *Ni* I (R) Fe I *Cd* I *Ru*
82	Th *Mo Fe* II—
83	**Fe** I (R) *Mo* (R)
84	*Ni* I (R) *Na* II—Fe I
85	*Zr* I—*Fe* II *Cr* I (R) *Cr* I (R)
86	*Mn* Rh I Fe I Cr I (R)—*Tm Fe* *Rh* I
87	*Co* I (R) **Fe** I—Si I *Mo*
88	*Mo Fe* I—Cr I (R) *Mo* Ru I
89	Bi I *Lu* Ta—*Co* I (R) *Mo*
90	Fe—*Tm V* I
91	*Ta Eu*—*Ru* Fe *Cu* Cr I (R)
92	*K* I (R) Re I— *Ni* I (R) *Mo*
93	*Ru* I Bi I—
94	Cr I **Fe** I (R) Ni I (R)—Cb *Ca* I *Ru* I
95	Cr I (R) *Co* I—
96	*Ir* I *Fe*—Cr I (R) *Ru*
97	*Ca* **Cu** I *Mo*—**Pt** I (R)
98	*Ru Cu* I—Cr I (R) *Ru*
99	*Fe*—**Fe** I Re I *Ca* I
3000	*Mo* Fe I—*Co* I *Mo* *Ca* I Cr I (R) **Fe** I (R)
01	*Mo*—*Ru* I
02	*Mo Ir* I Pt I Ni I (R)—*Fe* II Pd I (R)
03	Fe I *Os*—**Ni** I (R) *Ir* I
04	*Fe*—*Ru Fe* I
05	Cr I (R) *Fe Cd* I—*Hf* Co I
06	*Ru Ca* I
07	Fe I *Fe* I—*Mn*
08	**Fe** I (R) *Ru*—*Ru*
09	*Fe* **Sn** I *Ca* I—**Fe** I *Pd* I (R)
10	Gd—Cu I

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
3011	Ta *Mn* *Mn* Fe—Zr I Ta	3040	*Ru* I **Fe I**—*Mn* **Cr I (R)** Os *Fe* *Ta*	3072	*Fe* Zn I Co I (R)— *Co* I *V* (R) *Hf*
12	**Ni I (R)** *Cu* I *Fe*—Ta *Hf* II *Ru* I	41	*Mn*—*Fe* I *Mo* Fe I	73	*Tm* *Mn* *Ru* I—*Co* I *Cr* *Cu* I *V* I *Fe*
13	*Cr* I Os *Ru* I *Mo*— Co I (R) **Cr I (R)** Mo	42	Fe I *Tm* *Ru* *Co* I (R)—Pt I (R) **Fe I** *Mn* (R) *Ru* I	74	Os *Fe* *Mo* *Fe*—*Mo* Os
14	*Fe* I—*Mo* **Cr I (R)** **Cr I (R)**	43	*V* I *Mn*—Os *V* I *Os* *Mo* *Mo*	75	*As* I—**Fe I** Zn I
15	**Cr I (R)** Tm—Os *Co* I *Fe*	44	**Co (R)** *Cu* I *Os*—Mn Os	76	*Bi* I *Ru* I
16	*Re* I Fe I *Mn* Re— *Mo*	45	Ni I Fe—*Mn* *Fe* *Ru* I *Mn* Ta	77	Os Ta *Os*—Lu *Fe* *Mo* Os *Cr* I
17	Ru Os *Co* I—Co I (R) **Cr I (R)** Fe I *Pt*	46	*Be* II *Mo*	78	Fe Os *Ta* *Na* II Os *Fe* I—*Ti* I
18	**Os I (R)** *Hf* Zn I **Cr I (R)**—**Cr I (R)** **Fe I**	47	*Mn* *Ir* I *Mo* *Cr*— **Fe I (R)**	79	*Co* I—Mn *Ta* *Fe*
19	Ni I (R) *Be* I Os—*Be* I	48	*Co* I Fe *Ru*—*Ru* I *Mn* Ta Co I (R)	80	*Fe* *Mo*—Ni I *Ca* I Cd I *Ru* I
20	*Zr* II **Fe I (R)**—*Co* **Fe I (R)** **Cr I (R)** *Ru* I	49	*Fe* *Os*—Ta *Cr* I (R)	81	*Mo* *Mn* *Lu*—*Ta* *Mo*
21	**Fe I (R)** *Hg* I—*Cu* I **Cr I (R)**	50	*Al* Os—*Co* I *Tm* *Hf* **Ni I (R)** *Co* I	82	Gd *Mn* *V* I (R) **Al I** Re I—Co I (R) *Cd* I *Co* I
22	*Co* I—*Cu* I *Mn* *Mo*	51	*Os*—	83	*Ru* I—*V* I **Fe I** Rh I
23	*Hg* I—*Mo* Rh I	52	*V* I *Cr*—*Mo*	84	*Mo*—*Os*
24	**Fe I** **Cr I (R)**—Bi I *Cu* I	53	Fe *Fe* I—*Mo* *V* I (R)	85	*Ta* Mo
25	*Mo* Ta *Fe*—*Hg* I Fe *Ir* I **Fe I**	54	Ni I (R) *Mn*—*Al* *Co* I **Eu** *Ru* I *Os*	86	*Ru* *Os* *Mo* *Co* I— Co I (R)
26	*Tm* Co I Fe I—	55	*Os* Fe I *Mo*—*Fe*	87	*Mo* *Os* *Co* I
27	*Hg* I—Ta Gd *Mo* Pd I	56	*Na* II *Fe* V I (R)— *Lu* *Mo*	88	*Ti* II *Ir* I *Cu* I *Os* *Mo*—*Re*
28	*Rh* I *Cb*—*Ta*	57	*Hf* *Al* **Fe I**—*Mo* **Ni I (R)**	89	*Mo* *Ru* I—Co I (R) *Mo* *Ru* I
29	*Cr* I *Au* I *Fe* I *Ir* I— *Zr* I Sb	58	*Mo* *Ta* **Os I (R)** *Re* I	90	Os *Fe* *Ru* *Co* I Os *Os*—
30	**Fe** **Cr I (R)** *Cu* I Re I—*Fe* **Os I**	59	**Fe I (R)** *Ru*—	91	*Mg* I—**Fe I** *Ru*
31	Yb *Hf* II *Mo* Fe *Cr* I— **Fe I** Ni I	60	Co I *Ta* *Os* V I (R)— *Mo* *Fe* I	92	*Mo* *Ta*—*Mo* **Al I** V (R) *Na* II *Fe* *Al* (R) Mg I
32	*Ir* I—*Sn* *Os* As I Gd	61	*Mo* *Cr* I Co I (R) *Fe*	93	V II (R) *Fe*—Os *Re* I *Fe* I *Ta* *Fe* Cu I
33	*Fe* *Au* *Ru* I—	62	*Mn* Os *Co* I—	94	Cb II *Ru*—Mo *Fe* I
34	Gd *Ru* I Sn I Cr I (R) *Co* I—*Fe* I *K* I *Bi*	63	**Cu I**—*Ta* *Fe*	95	*Fe* *Ca* I *Ta*—*Mo* *Co* I Cr
35	*Bi* I *Mo* *Ru* I—Fe Zn I	64	*Mo* *Al* Co I— Ni I (R) **Pt I (R)** *Ru*	96	*Co* I—*Cr* *Ru* *Co* I *Fe* Mg I
36	Cu I *Mo* Pt I *Ru*—	65	*Mo* *Cr*—	97	*Mn* Ni I *Mo* Eu—*Fe*
37	Cr I (R) **Fe I (R)**— **Ni I (R)** *Ru* I	66	*Mn* Pd I *Os* *Al* **V I (R)** *Fe*	98	*Fe* I Co I (R) *Mo*— *Fe* *Tm*
38	*Ru* I *Co* I—	67	*Ge* *Fe* I *Cr* II **Fe I** *Rh* *Re* I—**Bi I (R)** *Sn* *Fe* *Mo*	99	Ni I *Ag* *Ru* I—*Co* I *Fe* I *Mo* *Cu* I *Fe* I
39	**Ge I** *Fe* **In I (R)**— *Co* I *Cr* I *Mo*	68	Fe I *Ru*—*Gd*	3100	*Mn* Fe I—Gd Re I Fe I *Ru* I *Mo*
		69	Ta—Os Re	01	*Mo* *Hf* II—Os **Ni I (R)** *Mn* **Ni I (R)**
		70	Mn—		
		71	*Re* *Mo*—Ba I (R) *Pt* I *Co*		

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements
3102	*K* I (R) *K* I (R) *V* II *Co* I—*Fe*
03	*Ta*—*Co* I *Co* I (R)
04	La II *Mg* II *Mg* II Os
05	*Ru* *Ru* I Ni I—*Co* I Os
06	*Ru* I
07	*Co* I—*Co* I *Ni* I *Ru* I *Fe*
08	*Ca* I *Cu* I Re I Os
09	*Hf* II *Cr* Os—*Co* I
10	*Co* I *Fe* *Fe*—*Ru* I *Mn* *V* II *Co* I *Fe* *Be* I *Cr* Re I *Be* I
11	Os *Co* I Eu—*Fe* *Ru* I
12	*Fe* *Mo*—*Ru*
13	*Ru* I Co I—*Fe* Ta
14	**Pd I Ni I**—*Os* Rh I
15	*Mn*—*Ta*
16	*Fe* I *Cu* I *Os*—Fe I
17	*Ta*—*Fe* *Ca*
18	*Ru* I *Os* Re *Co* I Os *V* II—*Cr* II *Ru*
19	Fe—As I *Cr*
20	*Fe* *Mn* *Cr* II Fe *Cu* I—*Ir* I *Fe*
21	*V* II Re I Co I (R)—*Co* I (R) *Pr* Rh I *Fe*
22	*Fe*—**Au I**
23	*Fe*—Rh I *Fe*
24	*Ru* I—*Ru* Ge I *Fe* Os Ta *Cr* II
25	*V* II—**Fe I** Hg I *Ru* I
26	*Cu* I Fe *V* II *Co* I—*Co* I *Fe*
27	Co I—
28	*Fe*—*Cr* II *Cu* I *Fe* Re I *Co* I
29	*Fe* *Os* Ni I Fe I *Na* II *Co* I—*Ta* *Ru* *Ru* I *Ta*
30	*Ag* *V* II *Fe* Be II—Ta Eu Cb *Rh* I
31	Be II Os *Cr* **Tm**—**Hg I Hg I**
32	*Cr* II *Co* I—*Fe* *V* (R) **Mo** (R) Ta *Fe* *Cr* *Ru*
33	Cd I *Fe* *V* II—Tm
34	**Ni I** (R) Fe I—*Hf* II
3135	Dy *Fe* *Na* II—*Hg* *Fe* I
36	**Ca I** *Fe*—*Ru* *Cr* II *Co* I
37	Co I (R) *Co* I—Rh I *Co* I
38	*Fe*
39	**Pt I**—*Fe* I *Fe* Co I (R)
40	*Cu* I *Os* Fe *Ir* I (R) *Ru*—*Co* I *Ca* I *Os* *Ru* I
41	*Dy*—Pt *Sn*
42	*Cu* I Fe I—*Mn* *Mo* La II **Pd I** *Fe*
43	*Fe*—Fe
44	*Ru* *Cr* *Hg* I Fe I—
45	*Gd* *Co* I *Fe* *Hf* II—*Cr* Ni I *Os*
46	*Fe* I—Cu I
47	*Tb* Co I (R) *Ru* I *Cr* II *Fe* *Mo* *Ta*—*Au* I *Fe* *Fe*
48	*Ta* Mn Fe *Cr*—
49	*Na* II *Co* I—*Cu* I
50	*Fe*—*Ru* *Ca* I *Ta*
51	Tm **Fe** *Rh*—Re I *Fe* I
52	*Os*—*Rh* Os Co I
53	*Fe* I *Fe*—Os *Fe* *Re* I *Ru*
54	*Fe* Co Co I
55	*Cr* *Fe*—Rh *Fe*
56	**Os I** (R) Fe—*Dy* Pt I *Cu* I Os *Ru* I
57	Fe I Os Tm *Fe*—Fe I *Fe* I
58	**Mo** (R) Re I *Fe*—Co I (R) Ca I *Ru* I
59	*Fe* *Ir* I (R)—*Cr* Co I *Ru* I
60	*Cu* I *Fe* *Fe*—Fe I *Fe*
61	Mn *Fe* I *Os*—*Co* I Os Fe I
62	*Fe* I *Cr*—*Ti* I *Ta* *Dy*
63	*Ta* (R)—*Na* II *Cr* *Fe*
64	*Fe* I—*Os*
65	Fe I—Fe I
66	*Fe* Fe—Os
67	Fe
68	Co I *Fe* Os Re I—*Ti* II Ru *Fe*
69	*Cr* I *Cu* I Co *Ca* I Dy
3170	Ta *Fe* II **Mo** (R)—
71	Fe I—*Fe* I
72	Fe I—Tm *Ta*
73	Os *Fe*—*Tm* *Ta* *Fe* *Fe* *Os*
74	*Ru* *Co* I—*Co* I *Fe*
75	**Sn I** Fe I—*Fe*
76	*Ru* *Ta* *Fe* I
77	*Ru* Co—*Fe* II *Re*
78	**Fe I** Os *Os* Mn—*Fe* *Fe*
79	*Ru* Cr Ca II—*Rh* I
80	*Fe* II **Fe I**—*Ca* I *Cr* II Fe I Ta
81	*Fe* *Ni* I *Fe* Os *Fe*
82	*Fe* *Co* I—Os *Ta* (R) Re I Fe
83	*Fe* II *Ni* I V I (R)—*Fe* *Sm* **V I** (R)
84	Ni I—*Ta* *Fe* I *Re* I Fe I
85	Os **V I** (R)—Re I Rh I *Co* I
86	*Ru* I *Co* I Ti I—*Fe* II Os
87	*Os*—*Fe*
88	Cr *Ru* I Co I—Fe II Fe I
89	Rh I Os—*Co* I *Na* II *Ru* I
90	*Fe*—*Fe* I *V* II *Fe*
91	Cb *Fe* *Ta* **Rh I** *Co* I—Fe I Ti I
92	*Cr* I *Co* I *Ta* *Fe*—Fe I *Fe* II
93	*Co* I Fe I *Fe* I—V I **Mo** (R)
94	*Cu* I Os Fe I *Re* I—*Rh* I *Fe* *Os*
95	*Fe* Os—Ni I
96	*Fe* II Fe—*Ru* **Fe I** Fe I
97	*Cr* II **Ni I** *Rh* I—*Fe*
98	V I (R) *Cr* *Fe*—*Co* I Ta
99	*Co* I—**Fe I** Ti I
3200	*Re* I *Ni* Fe I—Pt I *Fe* I
01	*Ce*
02	*Ni* I V I (R)—*Fe*
03	*Co* I—

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements
3204	Pt I **Re**—*Au* I
05	*Mo Fe* I—*Mo*
06	*Ta*—*Mn*
07	*Fe* I *Sm* II *V* I (R)—*Ta*
08	*Cu* I Fe—*Cr* II Mo (R)
09	*Cr* II Fe—*Ni* I *Ca* I
10	*Co* I Fe I *Fe* II—*Eu* Fe I
11	*Cr Fe*—*Fe* I Sm *Fe Fe* I
12	*Tm Na* II *V* I—Eu Mn *Re*
13	*Os Fe* II—Eu
14	**Fe** I *Rh* I Fe I—
15	*Mo Ca* I *Sm* II *Fe*—*Co* **Fe** I
16	Ta *Mn*
17	K I (R) Fe I *Cr*—K I (R) *Rh* I
18	*Rh* I—Sm *Sn Cr Tb Ce* **Pd** I
19	*Co* I—Fe I Fe I *Tb*
20	*Pb* Ir I
21	*Ce* II *Ni* I *Ta*—**Ni** I *Mo*
22	Fe I *Ba* I—
23	*Ru* I *Cu* I—Ta Os
24	*Co* I *Cu* I *Mn*
25	**Ni** I Cb—**Fe** I *Ca* I
26	*Mn Ru* I—*Cr* I *Fe* I **Ni** I *Co*(R)
27	*Fe* I Os *Ta*—Fe II
28	Mn *Fe* I—*Ru* I *Fe Fe*
29	*Fe* I *Cr* Os **Ta** *Mg* I—*Fe Be* I **Tl** I *Mo Fe Fe*
30	Fe I Pt I—Sm II *Mn* Ta **Fe** I
31	*Cu* I Os—
32	**Os** I (R) *Pb* Sb I—Os **Li** I (R) *Ru* I *Co* I **Ni** I (R)
33	Fe *Mo Cr* I—*Mn* **Fe** I
34	Os—Ti II Fe I **Ni** I *Ta* Os
35	*Mn Mo Tm*—*Co* I *Fe Cu* I *Re*
36	Fe I—*Ti* I Sm *Mn* Tm
3237	Co I *Mo Mn*—*Rh* I *Cr Ta*
38	*Cr*—*Cr* Ru Os *Ru* I
39	*Ti* I **Fe** I—*Ru* I Sm II Ta
40	*Pb* Tm *Mn Mo*—*Mn Cr* I
41	*Os Sm* II *Ru* I—Ir I Tm *Ti* II
42	Ta *Ru Y* II—**Pd** I Ta
43	**Ni** I (R) *Fe Cu* I *Fe Ru*—Mn Co I
44	*Cr* I **Fe** I—
45	**La** II *Ta*—*Cr* Fe I
46	*Fe*—Fe I *Co* I
47	*Co* I *Fe Cr* I *Fe* I *Cb*—*Eu* **Cu** I (R) Mn *Ag Mo*
48	Fe I Ni I—Mn Ta
49	*Fe* **La** II *Ni* I—
50	*Co* I *Ta Sm* II *Fe*—Fe I Ni I
51	*Mn* **Fe** I Dy—*Cr* Pd I *Cr Ti* II Pt I
52	*Os Tb Fe*—**Cd** I *Ti* II *Fe Mn*
53	*Cr*—Fe *Sm* II *Fe*
54	*Mn* **Co** I (R) *Lu* Fe Sm II—*Ru* I *Ru Fe Os Cr*
55	*Fe* II
56	**In** I (R) *Mn Mo Ru*—*Fe* Ta *Os*
57	*Fe* I—Fe I *Cr Na* II
58	*Co* I *Ru* I Tm *Mn*—**In** I (R) **Pd** I Re I
59	Re *Ru* I *Ta Cr*
60	Ta *Mn Fe Os* Ru I—*Co* I
61	**Cd** I *Fe*—*Re Tl* II *Ba* I
62	*Fe Fe* **Os** I (R) **Sn** I *Pb*—Os
63	Rh I *Co* I *Fe* I—*Ta*
64	*Mo*—*Fe* I Os *Mn Co* I
65	Fe I *Mo Co* I—**Fe** I **La** II
66	*Cu* I *Ir* I *Ru* I—*Tm Cr* I
67	*Au Tm*—Sb I *Mn* **Os** I (R)
68	*Ru* I Fe I *Cu* I—*Mn*
3269	*Ca* I *Ta* (R) Os *Fe* **Ge** I—*Fe*
70	*Mn*—*Cr Mo*
71	**Fe** I Ni I *Ta Fe*—Rh I *Fe* I *Co* I *Cr*
72	*Fe*
73	*Mn Zr* II *Ru* I *Ta*—*Mo* **Cu** I (R)
74	*Na* II *Tb Fe*—*Ca* I *Ru* I Ta
75	Os—*Ta Ta*
76	*V* II Fe I *Co* I—*Sm* II
77	*Co* I *Fe* II—*Os*
78	*Mn* Fe *Co* I *Lu*
79	*Co* I *Zr* II *Ta* (R)—*Fe Cu* I
80	*Dy* Fe—**Eu** (R) **Ag** I (R) *Cu Mn*
81	*Mo Fe* II *Tb*—*Ba* I *Lu Ni* I
82	**Zn** I (R)—Ni I *Cu* I *Ni* I *Fe*
83	*Co* I—*Fe* Rh I *Co* I
84	Fe I
85	*Mo Fe* II—*Na* II
86	*Fe* I *Ca* I *Cr Fe*—**Fe** I Ni I
87	*Fe Co* I **Pd** I *Ta Mo*—
88	*Fe Fe*
89	*Mo* Rh I *Yb*(R) *Fe*—*Rh*(R) **Yb**
90	Pt I Os—*Cu* I *Fe Mo* Fe I *Cr*
91	Tm—
92	Fe *Ti* I *Ta*—**Fe** I *Cu* I
93	*Tb Fe*—*Cr Co* I (R) *Ta*
94	*Tb Ru* I *Rh* I—
95	Ta—
96	*Mn Ru* I *Fe*—*Ru* I *Re* I *Mn Re* I
97	*Ru*—*Ru* I
98	*Sm* Fe I *V* I *Mn Cr Ru* I—*Co* I
99	*Fe Ru* I *Ti* I—*Ta*
3300	Rh I—
01	*Fe*—**Os** I (R) *Ru* I *Re* I Sr I **Pt** I
02	**Pd** I *Cr* **Na** I (R) Tm—Bi **Zn** I *Ta Cr* **Zn**(R) **Na** I (R)

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wavelength	Elements
3303	**La II** *Mn* *Mo* *Fe* II—*Fe* *Co* I (R) *Ru*
04	*Mo* *Cr* I *Ta*—*Ru* I *Ni* I
05	*Fe* *Cr*—*Mo* *Co* I **Fe I**
06	*Ru* I *Os* *Zr* II Fe II Sm II—
07	*Fe* *Mo* *Co* I *Fe*—Sr I *Cr* I *Cu* I *Ru* I
08	*Au* I *Ti* I *Co* I—*Mn* *Co* I
09	*Ti* I *Ta* *Tm* *Cr*
10	*Ni* I Fe *Fe*—*Tm* *Mo* Os
11	**Ta**—*Mn*
12	Lu *Co* I *Fe* *Ni* I—*Dy* *Co* I
13	*Mn*—
14	*Fe* I Co I *Mn* *Fe*—Fe *Mn*
15	Pt I *Ru* *Ru* I *Os*—**Ni I** (R) *Ba*
16	*Dy* *Ru* I *Mn*—*Cr* I *Tm*
17	Fe I *Cu* I Mn—*Ru* I Ta
18	*Ti* II *Cr* *Co* I—*Ta* *Ru* Ta
19	*Co* I *Fe* *Co*—*Cu* I *Co* I Dy
20	*Au* I **Ni I**—*Fe* I *Mn* *Fe*
21	*Be* I Be I *Sm* II *Cr* **Be I** (R)—*Co* I
22	Co I Sr I **Ni I** Fe Re I—*Ba* I (R) *Ti* II
23	**Rh I** *Au* I *Cr*—Fe Pt I *Mo*
24	*Cr* II *Os* *Fe* *Tb*—Fe I *Ru* I
25	*Co* I Fe I—*Mo* *Ta*
26	*Co* I *Cr* Zr II Co
27	*Mo* *Os* *Fe* I—*Ru* *Y* II *Sm*
28	*Co* I *Cr* II—Fe
29	*Co* I *Cr* I *Fe* *Ti* II *Co* I—*Fe* *Cu* I V I *Mg* I Sr I
30	*Fe*—Sn *Cr* *Mn*
31	*Rh* I Gd—Fe I *Fe*
32	*Ru* Mg I *Ta*—*Ru* *Cr*
33	Co I—Cr
34	Co I (R) Fe I *Eu*—Cr
3335	*Ti* II *Cu* Re I—*Ru* I Fe
36	Os I (R) *Fe*—*Mo* *Ru* Mg I
37	*Co* I **La II**—Fe Ta *Ru* I *Cu* I
38	Re I—Rh I *Fe*
39	*Tb* Fe I—Ru *Fe* I Co I *Cr* II
40	*Dy* *Mo* *Ti* II—Fe I
41	*Ru* *Co* *Cr* Hg I—*Ru* Fe *Co* I Cb(R)
42	*Fe* I *La* I Re I *Fe*—*Cr* II Co I
43	*Cr* I—*Mn* *Cr* *Ti* II *Ce* Pt I
44	Rh I Re I—*Cr* Ca I *Ru* I **La II** *Mo* *Ce* II
45	**Zn I** *Cr* *Ru*—**Zn I Zn I**
46	*Cr* Re I—*Ti* II Cr(R) Co I *Fe* I
47	*Mo* *Cs* I—*Ru* I *Cr* II Fe I
48	*Ru* *Co* I—*Ru* I Rb I
49	Ti II *Cb* Cr *Cu* I *Cr* *Au* Ti II—
50	Ca I *Fe* I *Ca* I Gd—Rb I
51	**Sr I** *Hg*—*Fe* I *Co* I *Cr* *Os* *Fe* *Ru* I *Cr* I
52	*Fe* I *Cr* *Fe* I—*Cr* *Ru* *Sc* II
54	*Fe* *Co* Co I (R) *Cu* I—Ti I
55	*Au* I Fe *Re*—
56	*Zr* II V I *Cr* *Fe* I Co I—*Fe* *Cr* *Co* I *Ba* I (R)
57	*Zr* II—*Mo* Os
58	*Mo* Cb—*Cr* II *Ta* Gd *Fe*
59	*Co* I *Ru* I *Ni* I *Cr* Co I *Fe* I—Lu *Sc* II *Fe* Rh I
60	*Cr* *Cr* II—*Fe* I
61	*Os* Ti II *Ti* I (R) *Mo*—**Ni I** *Co* I Ta Ca I *Fe*
62	*Ru* I *Ca* I Rh I *Cr* I Gd *Fe* *Ru* *Mo*—Tm *Cr* I *Co* I Ni I
3363	*Co* I—*Ni* I *Co* I (R) *Mo* *Fe*
64	Os *Co* I *Fe*—
65	*Cu* I—*Cr* V I **Ni I**
66	**Ni I** Sr I—*Ta* *Fe* *Ni* I *Fe* I
67	**Co I** (R) *Fe*—*Cr* I *Be* I *Ni* I
68	*Cr* II *Dy* *Fe* **Rh I** Ru I—*Sc* II
69	*Mo*—**Fe Ni I** (R)
70	*Os* *Cr* *Co* I *Ti* I—**Os I** (R) **Fe**
71	Ti I—*Ta* *Ru* I **Ni I**
72	*Fe* I **Rh I**—*Tb* *Ti* II
73	**Pd I** (R) *Co* I—*Co* I *Ru* I
74	**Ni I** *Co* I—*Tm* *Cr* *Ru* I *Cr*
75	*Mo* *Cu* I
76	*V* I *Cr* La II *Ni* *Cr*—*Fe* Lu *Ba* I (R)
77	Co I *Ce* *Fe*—*V* I
78	*Ru* *Cr* II *Co* I—*Os* Fe *Co*
79	*Fe* I *Re* *Cr* I—*Ru* I *Re* I *Mo*
80	Fe *Ru* I—**Ni I** (R) Pd I Sr II Ni II La II
81	*Fe* I *Cu* I Co I
82	*Cr* Sm II *Fe* I—*Cr* II Nd **Ag**(R)
83	*Sb*—Fe I *Ti* II *Co* I Fe I
84	*Os* *Cr* I—*V* I *Mo*(R) *Cr* I
85	*Ru* Co I (R) *Cr*—*Ru* I *Ti* I
86	*Cr*
87	*Fe*—*Fe* Os I *Ti* Zr II
88	*Zr* II—*Fe* *Ru* I *Cr* I
89	*Ru* I *Fe* I
90	*Co* I—*Cr*
91	**Ni I**—*Ru* Zr II
92	*Fe* Fe I—Ru **Fe I** **Ni I** (R)
93	*Fe* I—Dy *Mo* *Cr* II *Fe*
94	*Fe* I—*Ti* II Fe I
95	**Co I** (R) *Cu* I—
96	*Cu* I—Eu **Rh I** Fe I
97	*Lu* Bi I—Tm *Fe* I *Mo*

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

Principal Lines by Wavelength

Wave-length	Elements
3398	*Co*
99	*Fe* I Re I Fe I Zr II *Ru*—**Rh** I *Hf* II *Tm*
3400	V I—
01	*Ni* I—Fe I Ru I Os I *Co* I
02	*Cu* I Fe *Cr* II *Sm* II—Os I *V* I
03	*Cr* II *Mo* *Ni* I—*Cr* **Cd** I
04	*Fe* I *Mo* Fe I—**Pd** I (R) Re I
05	**Co** I (R) *Cb*—*Bi* I *Co*(R) *Ru* Re I *Mo*
06	*Fe*—*Rh* I *Ru* *Ta* Fe I *Ta*
07	*Cr* **Fe** I—Gd(R) Dy
08	*Cr* Pt I—Re *Cr* II
09	**Co** I (R) *Fe* Ru *Cr*—**Ni** I
10	*Fe* *Zr* II—*Fe* I
11	*Cr* *Fe*—*Ru*
12	**Rh** **Co** I (R)—**Co** I (R) *Fe* *Ru* I
13	**Fe** I *Cu* I **Ni** I—*Tb* **Ni** I
14	*Ru* I Co I **Ni** I (R)
15	*Co* I *Fe* I Co II (R) *Cb*
16	*Ru*—*Gd*
17	**Co** I (R) *Fe* *Fe* I—*Co* I *Co* I Fe I
18	*Sm* II Fe I *Gd*
19	*Re* I—*Fe* *Ta*
20	*Ru* *Cu* I *Tb*—*Ni* I *Co* I
21	*Cr* II **Pd** I (R) *Ni* I—*Co* I
22	*Gd* *Fe*—Fe I *Cr* II
23	**Ni** I (R)
24	Fe I—*Co* I **Re** I
25	*Fe* *Eu* Tm—Tm *Cb*(R) *Cr*
26	*Fe* *Fe* I—*Fe* I
27	*Fe* I—*Re* I *Cr* *Os* *Pt* I
28	*Fe* I Co Ru—*Fe*
29	*Dy*—*Ru* *Co* Tm
30	*Zr* II *Ru* I *Ta*
31	*Tm* *Cr*—**Co** I (R) *Fe* *Cr*
32	*Ru* I *Co* I *Cr*—*Ru* *Gd*
33	**Co** I (R) *Fe* *Ru* I *Cr* II **Pd** I—**Ni** I (R) *Cr* I
3434	*Cr* I *Dy*—*Mo* **Rh**(R)
35	*Ru* I—*Cr* I *Cr*
36	*Ta* *Cr* I—**Ru** I (R)
37	*Fe* *Mo* **Ni** I (R)—Co I Re I *Fe*
38	Zr II *Fe* *Ru* I—*Co* I *Co* I *Mn* II
39	*Gd* *Cr*—*Gd* *Fe* *Gd*
40	Ru I—*Cu* I **Fe** I **Fe** I
41	*Cr* I **Pd** I *Cr* I *Dy*—Tm *Mn* II
42	*Fe* I—*Fe* I **Co** I (R)
43	*Co* *Mo*—**Co** I (R) *Cr* **Fe** I
44	*Ti* II *Os*—
45	**Fe** I—*Os* *Dy* Cr Sm(R) *Cb* *Fe*
46	*Ru* *Co* I **Ni** I (R) *Tb* *Ru*—K I (R)
47	*Dy* *Cr* I *Mo*(R) Fe I Zr I *Cr* I—K I (R) *Rh* I *Cr* I
48	*Ru* *Ir* I
49	**Co** I (R) Os Re(R) **Co** I (R)—
50	Rh I Fe I Cu I Gd—*Cr*
51	*Rh* *Gd*—*Fe* I Re I Fe I
52	*La* II Fe I—**Ni** I (R) *Ru* I
53	*Fe* *La* II *Cr* I—**Co** I (R) Tm *Cr* I
54	*Tb* Dy—*Cu*
55	*Os* *Be* I **Rh** I **Co** I (R) *Cr* *Rh* I—*Cr*
56	*Ho*—*Dy* *Ru* I *Co* I
57	*Tb* Rh I *Fe*—*Cu* I Rh I
58	*Co* I *Cr* *Fe* Os **Ni** I (R)—
59	Os *Cu* I *Fe*—*Fe* I
60	*Mn* II *Cr* I **Re** I—**Pd** I (R) *Mo* Dy
61	Co I—*Ti* II **Ni** I (R)
62	**Rh** I Tm *Fe* I—**Co** I (R)
63	*Ru* I *Fe* I—*Ta* Gd
64	Yb(R) Sr II—Re I Cr
65	*Cr* *Cu* I *Os*—*Cr* **Co** I (R) **Fe** I
66	Cd I—*Fe* I *Fe* I
3467	*Cr* I *Ru* Gd—**Ni** I **Cd** I *Cr* Re I
68	*Tb* *Dy*—*Fe* II *Cr* *Fe* I *Co* I Gd
69	*Fe* *Ag* *Mo* **Ni** I—*Cr* I Rh I *Fe* I
70	*Cr* I—*Cr* I **Rh** I
71	*Fe* I *Fe* I *Co* I *Cr* I—
72	*Cu* I *Ru* Rh I *Lu*—**Ni** I (R) *Cr* I *Tb* *Cr*
73	*Gd* *Fe*—*Cr* I *Dy* *Ru* I
74	**Co** I (R) *Mn* II *Cr* *Fe* —*Co* I Cb *Ca* I **Rh** I *Cr* I *Sr* II
75	**Fe** I—*Fe* I *Cu* I
76	*Yb* *Fe* I Co I (R)—**Fe** I Cs I
77	*Dy* *Cr* I *Ti* II—*Fe*
78	Os *Co* I *Fe* *Co* I *Cr* I *Hg* II **Rh** I
79	*Cr* I *Cr* I (R) *Zr* II *Mo*—
80	*Co* I *Cs* I *Cr* I *Re* I—*Ta* *Re* I
81	*Zr* II **Pd** I (R) *Ru* I Gd—*Cr* *Gd*
82	*Mn* II
83	*Fe* I *Ru* *Ru* I Co I (R) *Pt*—*Cu* I **Ni** I (R) *Mo*
85	Pt I Fe I Co—Ni I
86	*Cr*—
87	*Os*—*Cu* I Ca I *Co* I
88	*Cr*—*Mn* *Cu* I
89	Co I (R)—*Fe* Pd I
90	**Fe** I *Co* I
91	Co I (R)—*Gd*
92	**Ni** I (R)
93	**Ni**(R) *Fe* II—
94	*Ru* I *Gd* *Rh* I Dy—*Cr*
95	Fe I—**Co** I (R) *Mn* II *Fe* *Ru*
96	Zr II—Co I (R) *Co* I
97	Fe I—Fe I *Ta*
98	*Cu* I—*Os* *Dy* **Rh** I **Ru** I (R)
99	*Sr* I
3500	*Cd* I *Tb* *Cu* I—*Fe* *Tb* **Ni** I
01	**Ba** I Os—

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
3502	Co I (R) *Cr*—**Rh I** Ni I *Co* I	3541	Fe I *Cb*—*Ru Rh* I	3585	Dy *Co* I Fe I—Fe I Dy
03	*Re* I—*Ta Cr*	42	Fe I *Fe* I *Dy*—*Ag* Os	86	*Fe*—*Mn Au* I Fe I
04	*V* II—*Dy* **Os** I *Fe* I *Ta*	43	*Co* I *Fe*—*V* I *Fe Tb* Rh I	87	Rb I Co I (R) *Fe Os* *Fe* I—*Fe* I Ni I
05	*Fe Dy*—*Gd V* I	44	*Mo Fe Ba* I *Cu* I	88	*Fe* I *Fe* I
06	Co I (R) *Fe* I—*Dy*	45	*Fe* I Gd	89	*Cb Fe* I *Ru* I Cb *Fe* I —*V* II
07	**Rh** I Lu *Tb*—Ni I	46	*Tb Dy*	90	**Nd**—*Ce*
08	*Ag* I *Mo Fe*—*Fe* I	47	*Fe* I—Zr I *Ba* I *Mn*	91	*Fe* I Dy *Fe*—*Rb* I *Dy* *Au*
09	Tb—*Ru* I Co I (R) *Fe* I	48	*Fe* I *Mn Fe Sr* I **Ni** I *Mn*—	92	*V* II *Dy Fe*—*Fe* I *Gd* *Y* I
10	*Tb* **Ni** I (R) *Fe* I—*Cr* Bi I	49	Gd—Rh I *Fe* I	93	*Ru* I *Fe* Cr I (R)—*Cb*
11	Ta *Cb*—*Rh* I *Cr* II	50	Dy—Co I *Cr* I	94	*Cu* I *Au*—Fe I Co I
12	*Cu* I *Fe Re* I— Co I (R) *La* II	51	*Ni* I	95	Dy *Mn Fe* I—*Ta*
13	*Fe* I *Rh* I Co I (R)— Ir I **Fe** I Ni I	52	*Fe*—*Co* I *Fe* I *Co* I	96	*Ti* II *Dy* Bi I Rh I *Fe* *Tb*—
14	*Ru* I—*Fe*	53	Pd I (R) *V* I *Ni* I— *Au* I Fe	97	*Fe* Rh I—**Ni** I (R)
15	**Ni** I (R)—*Be* I	54	*Fe Lu*—**Fe** I	98	*Cu* I *Au* I *Os* I—*Ti* I *Fe*
16	*Fe*—*Fe Re* **Pd** I (R)	55	Nd *Cr*	99	*Cu* I *Fe Cr Ba* I—*Fe* *Fe*
17	*Cu* I *Dy Re*—	56	*Cr* II—**Fe** I	3600	*V* I—Y II
18	*Co* I—*Ni* I *Fe* Os	57	*Fe*—	01	**Zr** I—*Cr* I *Os*
19	**Tp** I (R)—**Zr** I *Ru Tb* Ni I	58	**Fe** I Gd(R) *Cr Co* I *Re* I *Ir* I	02	*Cu* Co I *Fe* I Ni I *Fe* —*Fe* I *Mo*
20	*Cu* I Co I *Ru*—*Fe*	59	*Fe* Os I	03	Eu Fe I—*Fe* I
21	*Eu* **Fe** I—Co I (R) *Fe* I	60	*Fe* Ce Os I (R) Co I	04	*Fe Fe*—*Gd*
22	*Fe* I—*Fe* I	61	*Hg*—Tb *Ni* I	05	*Fe* I Cr I (R) *Co* I *Fe* I—
23	*Fe* Co I (R) **Ni** I—Os	62	*Cr Os*—	06	Dy—Fe I *V* I *Eu* Ni I (R)
24	*Fe Cu* I *Fe* I—**Ni** I (R) *Ba* I	63	Dy *Nd*—*Dy*	07	*Ta*—*Mn*
25	*Tb Rh* I	64	*Fe* I—*Fe Cr* Co I	08	*Fe* I *Mn*—Gd Tm **Fe** I
26	*Os Fe* I *Fe* I *Fe Fe* I— *Fe* I Co I (R)	65	**Fe** I—*Fe* I *Au* I	09	*Cu* I Ni I *Cr Sm* II— **Pd** I (R)
27	*Ta Cr*—*Cu* Fe I Ni I	66	*Cr* **Ni** I (R) *Tm*—*Pd* *Ta*	10	*Cr* Ti I Fe I *Mn* **Ni** I (R)—**Cd** I *Fe* I *Cu* I
28	**Rh** I—**Os** I (R) *Ru* I	67	*Fe* I *Fe* I—Lu	11	*Ba Tb*—Cs I *Co* I
29	Co I (R) **Tl** I— Co I (R) Fe	68	*Fe* I—*Tb Fe Fe* I Dy	12	*Fe* I Rh I—*Cr* **Ni** I Cd I *Fe* I
30	Os *Cu* I *Fe* I—*Ni* I	69	Co I (R) *Mn*—Os	13	*Fe*—*Cu* I
31	*Ru*—Dy *Mn*(R) *Mn*	70	*Mn*(R) **Fe** I *Mn*(R) **Rh** I (R) *Fe*—	14	*Fe Cu* I *Mo Cd* I—*Fe* *Fe*
32	*Mn*—*Fe* Os I *Ru*	71	*Fe* I—**Ni** I (R) Fe I	15	*Fe*—*Cr* I *Tb Fe* I
33	*Fe Na* II *Fe* I Co I— *Cu* I	72	*Zr* II Pb *Cr* I	16	*Fe* I Os I
34	*Fe* I Dy	73	*Fe*—*Cr* I *Fe Dy Mo Fe*	17	*Re* I *Ir* I *Fe Cs* I—Fe
35	Cb—*Tm Ru*	74	*Cr* I Dy—Co I	18	*Fe* I—*Dy* **Fe** I
36	Dy *Fe* I—Fe I *Ru Tm*	75	*Fe* I *Fe* I Co I (R) *Fe* —Zr I *Cb Fe* I		
37	*Re* I *Fe* I—*Fe* I *Fe* I *Ru* I	76	Dy—*Fe* Dy		
38	Rh I *Rh* I *Ag*—Dy	77	Ce—*V* I *Mn* Dy		
39	Ce II—*Ru* I	78	*Fe* I—Cr I (R)		
40	Fe I *Tb*—*Fe* I	79	*Re* I *Tb*—*Ba* I		
		80	*Dy Au Re* Cb—*V* I		
		81	**Fe** I (R)—		
		82	*Fe*—*Cr Mo*		
		83	Re I Rh I *Fe*—*Fe V* I		
		84	*Ta Dy*—Fe I *Co* I *Fe* Gd		

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements
3619	*Mn Fe* **Ni I** (R) *Os Cr*—
20	*Dy Er Cu* I *Fe*—
21	*Sm* II *Cu* I Fe I—*Fe*
22	Fe I—
23	Fe I *Fe* I—*Fe* I *Mn*
24	*Zn* Ca I *Cu* I *Fe* I *Mo* —*Ag* I Ni I *Fe Ti* II *Co* I
25	*Fe* I *Ta*(R)—*Tb*
26	*Mo Cr*—Rh I Ta *Sm* II
27	*Fe*—*Fe* Co I
28	*Fe* I **Pt I** Tb—*Ir* I *La* II
29	*V* I Dy—Mn
30	*Fe* I—*Ba Sc* II Ca I *Ca* I *Pr*
31	*Fe* I *Na* II *Co* I **Fe I**—*Co* I
32	*Fe*—*Fe Cu* I *Cr Co Fe* I
33	*Fe Y* II—*Fe*
34	Sm II *Fe* I—*Fe* **Pd I** (R) *Co Ru Ni* I *Cr*
35	*Mo Fe* I *Cr* I *Mo* Ti I —*V Cu* I
36	*Fe* I *Ir* I *Fe* Zr II—*Cr* I *Fe Co* I *Ba Fe* I
37	*La* II *Fe* I *Co* I—*Re* I *Fe* I
38	*Mo Fe* I *Tb*—Pt I
39	*V* I Co I—Rh I *Zn* **Pb I** *Cr* I
40	Os I *Cr* I **Fe I**—
41	V I *Ti* II *Mn Cr* I—*Pr Tb Cu* I *Co* I *Cr* I
42	Ta—**Ti I** *Sc* II *Au* II *Fe* Re I
43	*Fe Pt* I *Co* I—*Fe* I *Tm Fe* I *Fe*
44	Ca I—*V* I *Ca* I *Fe*
45	*Fe* I *Co* I *Fe Cu* I *Sc* II *Tb* La II **Dy** *Fe* I—*Fe*
46	Gd *Ti* I *Pr*—
47	*Co* I *Fe* I—Co I *Tb* Lu **Fe I**
48	*Co*—Os *Dy V* I *Cr* I
49	*Fe* I Co—Sm II Fe I *Cd* I
3650	*Fe* I Hg I La II *Fe* I *Tb*
51	*Fe* I *Co* I **Fe I**—*Sc* II
52	*Cu* I—**Co I** (R) *Fe* Tl I
53	**Ti I**—*Fe* I Cr I
54	*Cu* I *Co* I Os—*Mo* Ti I Gd *Tb*
55	*Fe* I—*Fe Sn Cu* I
56	Gd *Fe Cr* I—*V* I Os I *Co* I
57	*Fe* I *Mo*—*Fe* I **Rh I**
58	Ti I—*Fe* I Tb
59	*Mo*—Fe I *Ti* II
60	*Fe* I *Mn*—*Ti* I
61	Sm II *Ru* I *Fe* I—*Ir* I *Ni* I
62	*La* II *Co* I *Sm* II Gd —*Ba Cr* II *Fe Hg* I
63	*Pt* I *Tb Cr* I *Fe* **Hg I** *Fe* I—V I Zr I
64	**Ni I**—Fe I *Y* II *Ir* I Gd *Tb Fe Mo*
65	V I—*Cu* I *Cr*
66	*Rh* I *Fe* I—*Cr* I
67	*Fe*—*V* I *Ce Fe* I
68	*Tm Fe* I—Pr *Fe* Ti I
69	*Fe* I Ni I *Ru*—Fe I *Yb Mn*
70	*Fe* I *Co* I Fe Ni I—*Mn Fe* I Sm II Os I
71	V I Gd—*Pb* Ti I *Cu* I Pt I
72	Dy V I—*Mo*
73	*Fe* V I—
74	*Pt* I *Sm* II Gd Dy Ni I *Fe*—Zr II *Fe Ir* I
75	*Yb Ca* I *Mo*(R)—*Mn* V I
76	Fe I *Cr* Tb—Co *V* I *Cu Fe* I *Mn*
77	*Fe*—*Fe Tb*
78	*Ca* I *Eu*—*Tm* Fe I *Fe* I
79	*Cr*—*Cr* **Fe I**
80	V I—*Mo Mo Fe*
81	*Fe*—
82	*Mn* **Fe I** *Tb Ag* I—*Au*
83	Co I (R) Fe I V I **Pb I** *Zn* II—
84	**Fe I** Gd Co I *Cu* I
85	Ti II *Pr*—
86	Fe I *Fe* V I Gd—*Cr* I
3687	*Pr Fe* I *Pr* **Fe I**—*Fe* I Gd *Sm*
88	V I Ni I **Eu II** *Fe*—*Mo*
89	Os Fe I—Re I *Fe* Ti I
90	V I **Pd I** *Fe*—Rh I *Co* I *Fe*
91	*Tb*—Re I
92	*Sm* II V I (R) **Rh I**—*Fe Mn*
93	*Fe Co* I *Co* I—*Mn Ni* I Sm II
94	**Fe I Yb**(R) *Ti* I—*V* I *Tb Mo*
95	Fe V I—V I
96	Mn *Ru* I
97	Fe I—Re Gd *Cb*
98	*Zr* II—*Fe*
99	*Fe* I—Gd *Pt* I
3700	*Ti* Tm—*Cu* I *Sm* II Rh I *Sm Ru*
01	**Fe I** Tm *Hg* I—*Mn*
02	*Fe* Co *Ti* I *Fe* I—*Tb*
03	Os—*Fe* I V I (R) *Fe* I *Fe Tb*
04	**Co I** (R) *Hg* I *Ti* I Fe I—V I (R)
05	V I—**Fe I** *La* II *Ca* II *V* I *Mn*—*Os*
07	Fe I *Co* I—Ti I *Fe* I *Fe* I
08	*Fe* I *Ti* I *Sm* II V I *Co* I
09	*Ag* I **Fe I** *Zr* II—*Fe Ti* I
10	*Mo Y* II—Sm II (R)
11	*Fe* I *Fe*—*Co* I Tb
12	*Cu* I *Co* I—Gd Sm II *Os Fe*
13	Cb Rh I *Eu*—La II Gd Os V I
14	*Pr*—*La* II
15	*V*—La II *Fe* I
16	Gd Fe I—*Cr*
17	Re I *Ti* I Gd—Tm
18	*Fe* I—*Li* I Sm II **Pd I** *Mn*
19	*Sm*—**Fe I** (R)
20	*Os* I—*Cu* I
21	*Fe* I—*Fe* I *Fe Ti* II Sm *Fe V* I
22	*Gd* Ni I—**Fe I** Ti I

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wavelength	Elements
3723	*Mo*
24	Fe I—Ti I Eu
25	*Tm* Ti I *Ir* I *Gd Fe*—*Mo*
26	*Co* I Sm II (R) Fe I Ru I
27	*Fe* I—Fe I *Mo*
28	Ru I *Ir* Sm II—*Fe* I *Mn*
29	*V* I *Cd* I (R)—**Ti** I
30	*Fe* Co I (R)—*Ni* I *Cr* I Gd *Fe*
31	*Ta Sm* II *Ir Fe*—*Mn*
32	*Cr* I Co I (R) Fe—V(R) Os(R)
33	**Fe** I Co I—
34	Tm *Co* I—Ir *Co* I **Fe** I (R)
35	*Rh* I *Fe* I—Co I (R) *Sm* II
36	*Be* I—**Ni** I *Mn Ca* II
37	*Rh* I **Fe** I (R) *Rh*—*Mo V* I
38	Fe—*Ir* V I
39	*Fe* I *Pr* Ni I *Fe* I—*Fe* Gd Cb Pb *Zn*
40	*Gd Fe Re* I *Co* I V I *Fe*—
41	Ti I (R) *Th Cu* I—*V* I
42	*Ru* I *Mo*—*Fe* I *Ru Cr* I
43	Fe I *Cu* I—*Cr* I *Sm* II *Cr* I
44	Tm *Fe* I *Mo Cr* I—
45	*Mo*—Co I (R) **Fe** I Fe I
46	Os—*Mn Fe*
47	Ir I—*Dy V* I
48	*Ho* Rh I **Fe** I *Ca* I—*Cr* I *Fe* I Cr I (R)
49	*Ni* I **Fe** I (R)—*Co* I
50	*Ca* I—*Mn*
51	Co I *V* I *Tm Fe* I
52	*Fe* I—Os I (R) Ti I
53	*Ca* I—*Dy* Fe I *Ti* I *Dy*
54	*Co* I—
55	*Mo Tb* Co I—*V* I
56	*Fe Th*(R)—*Mn Fe*
57	*Cr* I Dy *Fe*—*Cr* I
58	*Cr* I **Fe** I—*Mo*
3759	**La** II Ti II *V* I *Cu* I—*Co* I
60	Fe I *Co* I—Fe
61	Ti II Tm *Fe* I—Pr Tm
62	*Fe* I—
63	*V* I *Mn*—**Fe** I *Mn*
64	Pr
65	Rh I *Tb*—Fe
66	Os—
67	**Fe** I *Ru Cr*—*Tb*
68	*Fe* I *Os Cr* I—*Ir* I *Cr* I *Pr*
69	*Gd*—Nd *Fe* I
70	*Fe* I—*Gd*
71	*Sm*—*Ti* I *Cu* I *Mo*
72	*Pr*
73	*Fe* I
74	Pr *Eu Os*—Co I *Os* Fe I
75	**Ni** I **Tp** I
76	*V* I *Os* Fe Tb—*Mn* Os
77	*Fe Fe* I—Co I *Ru* I
78	*Ni* I *Fe* I—*Fe V* I *Fe* I
79	Fe I—*Mo*
80	*La* II
81	*Ru Fe* I—*Mo* Pr *Fe*
82	*Fe* **Os** I (R) *Fe* I—
83	**Ni** I *Sm* Pr
84	Ta—
85	*Pr*—*Fe* Fe
86	*Ru* I Fe I—Fe I
87	*Nd Fe* Sm II—*Re* I **Fe** I
88	Dy *Rh*—*Cr* I *Pr*
89	*Fe Ti* I—*Cr* I
90	Fe I *Os* I Cb(R) Mn *Cr* I *Cr* I—*Ru* I *Ir* *Os* **La** II
91	*Cb Cr* I—*Fe* I *Fe*
92	*Ta Cr* I *Fe* I *Ni* I—Pr *Fe* I
93	Rh I *Cr* I *Fe* I *Fe* I—*Ni* I *Fe* I *Cr* I Os I *Zn* II
94	*Fe Pr*—*Cr* I *Li* I **La** II *V* I
95	**Fe** I—Tm *Au* I
96	Gd—*Re* I
97	*Cr* I—**Fe** Cr I
98	*Cb* **Mo** I (R)—**Fe** I *Ru* I
3799	Eu II Pd I *Mn Ru* I (R)—**Fe** I *Pr V* I
3800	Ir Pr *Os*—*Cu* I *Mn* Sn
01	*Cr Nd*—*Hg* I *Fe Fe Mo Mn Fe* I
02	*Fe*—*Cb*
03	*Pr V* I—
04	*Au* II *Fe* I—*Mo* Cr I
05	*Cu* I **Fe** *Nd*—Co I
06	*Fe*—Fe I *Mn Rh* I *Cr Tb*
07	**Ni** I *Sr* I—*V* I Fe I *Cr* I
08	Co I—*V* I *Ru* Fe I
09	*Pr* Mn—*Fe* Mn *V* I
10	*Fe* Ag I
11	*Co* I—*Fe* I
12	Gd(R) *Cr* Co I—**Fe** I
13	*Be* I *V* I—*Fe Fe* Co I(R) Gd
14	*Co* I—*Fe* I *Cr Fe*
15	*Cr*—*Ce* **Fe** I
16	*Au Cr* I *Co* I *Fe* I *Co* I—*Mn* Dy *Co* I
17	*Ru Tm*—*Fe Cr* I *Co* I
18	*Rh* I Pr *Cr* I—
19	*Ru* I—*Cr* I **Eu** II *Co* I *V* I
20	**Fe** I—*Cu* I
21	Fe *V* I—*Nd Pr Fe* I
22	*V* I *Ru* Rh I—*Mo*
23	Pr—*Mn Cr* I *Mn*
24	*Fe* I *Fe* Fe I—
25	*Cu* I *Cr* I—*Au* II **Fe** I
26	*Pr Cr* I—*Mo Fe*
27	*Os Mo*—Fe I
28	*Nd* Rh I—*Mo*
29	Mg I *Au Nd Fe*—*Mn Fe*
30	Cr I *Sm* II—Pr *Fe* I *Fe* I
31	*Nd Cr* I—**Ni** *Ru*
32	Pd I Mg I—*Ni* I
33	*Nd* Fe I—*Mo Mn Ir*
34	**Fe** I *Re* I *Mn*(R)—*Cr* I
35	*Ru*—*V* I
36	Os I *Cr* I Fe *Au*—*Th* Dy Gd *Sm Nd*
37	*Fe* I—

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
3838	*Tm* **Mg** I—*Nd*	3879	Pr *Cr* I—*V* I	3918	*Ce* *Mn* *Fe* I *Fe*—*Fe* I Pr
39	*V* I Fe—*Ru* Mn	80	*Pr*—	19	*Fe* I **Cr** I (R)—
40	*Tb* Os **Fe** I—*La* II *Ag* I	81	*Cr* I—*Cr* I Os **Co** I (R)	20	*Co* I **Fe** I—*Co* I
41	**Fe** I *Mn* Lu Cr I Dy *Co* I—	83	Tm *Fe* *Cr* I *Zn* I Tm—*Cr*	21	Cr I—**La** II Zr I
42	**Co** I (R) *Pr*—*Fe*	84	*Fe*—Co I *Eu*	22	*Sm* II *V* I—*Mn* *Tb* Co I Ta **Fe** I Ta Pt I
43	Fe *Re* I *Re* I—*V* I *Os* *Co* I *Mn*	85	Pr *Cr* I *Co* I *Cb*—Fe I	23	*Ru*—
44	*Fe* V I—*Pr*	86	**Fe** I **La** II—Cr I	24	*Mn* Pr—*Ti*
45	Fe I **Co** I (R)—*Fe* *Mo*	87	*Tm*—	25	*Fe* I *Cu* I *Pt* I Tb Pr—*Fe* I *Ru* I *Fe* I
46	*Fe*—*Pr* Fe I	88	*Bi* I—Cs I *Fe*	26	*Mn*—*Cr*
47	*Mo* V I—*Nd*	89	*Ba* Pr *Mn*—*Ni* I *Ce*	27	*Nd* *Pr*—**Fe** I *V* I
48	**Tm** *Mg* II *Fe* *Mo*—Tb Sm *Cr* I	90	V I *Fe* Zr I—*Fe*	28	*Fe* I *Sm* II—*Os* Cr I
49	La II *V* I *Cr* I—*Cr* I Os I **Fe** I	91	Ho *Sm* II *Cb* Zr I—*Ba* II Fe *Cr* I	29	*Fe* *Fe* **La** II *Mn*—*Tm* *Cr* Re I *Ti* I *Os*
50	*Cr* I (R) *Ru* I—Fe I *Pr* Co I	92	*Co* I *Ru* I—*Mn* *V* I *Fe*	30	*V* I **Fe** I Eu—**Eu** II (R)
51	*V* I—Pr	93	*Fe* I Fe I—*Fe* I	31	*Fe* I—Dy *Ru*
52	*Cr* I *Nd* Gd—Fe I Pr	94	*Fe* *Cr* I **Co** I (R) Pd I — Gd *Mn* **Co** I (R)	32	*Fe* I *Fe*
53	Dy *Cr* I Os *Fe* I *Mn*—	95	*Ti* I—**Fe** I	33	*Sc* I—Sm II Fe I *Ag* *Co* **Ca** II (R) *Ce* *Co* I
54	Sm *Cr* I—*Cr* *Pr*	96	*Sm* II	34	V I Rh I—Gd I *Nd* Ir I
55	*Cr* I *V* I (R)—*Cr* I V I	97	*Fe* I—*Cr* I *Au* I Fe	35	*Tb* *Fe* I—*Ba* I (R) Fe I Pr **Co** I (R)
56	*Cr* I **Fe** I *Ru*—*Rh* I *Co*	98	*Fe* I *Ce* *Mn* *Co* I (R) —Dy	36	La II—*Mn*
57	Os I—*Ru* *Cr* I	99	*Fe* *Fe* I Tb—**Fe** I	37	*Pr* *Fe* I—*V* I *Ba* I
58	**Ni** I (R)—*V* I *Cr* I	3900	*V* I *Os*—Zr I *Fe* I *Tm* *Yb*	38	*Cr*—Os
59	Fe I—**Fe** I	01	*V* I *Ru* I *Tb*—Os	39	*Os* Tb
61	**Co** I (R) *Fe*—*Cu* I	02	*Cr* Gd *Pr*—Cr I **Fe** I **Mo** I (R)	40	*Pr*—Fe I Co I
62	*V* I—*Cr*	03	*Cr* I *Sm*—Fe I	41	*Cr* *Fe* I Cr I (R)—*Nd* Co I *Sm* II
63	*Co* I *Fe* I	04	*Ti* I	42	Fe I—Gd *Rh* I *Ce* *Mn*
64	**Mo** I (R) *Zr* I La II —V I (R)	05	*Si* I *Gd*	43	*Eu* Fe I—*V* I
65	Be I Pr(R) *Sr* I Os I —*Be* I **Fe** I	06	Co I *Hg* I **Fe** I—*V* I *Fe*	44	**Al** I—Dy *Fe* I
67	Fe I—*V* I *Ru* I *Fe* I	07	**Eu** II (R) Gd *Fe* Sc I —*Cr* Fe	45	*Fe* Co I *Cr*—Gd *Ru* *Cr*
68	*Ti* I *Dy*—*Dy*	08	Pr *V* Pr—Cr I	46	*Ir* I—Tb
69	Fe I Dy	09	*Au* I—*Fe* I *Fe* I *V* I *Ba* I (R) Co I	47	*Fe* I *Co* I—*Fe* I Pr *Ti* I
70	*Cr* I—*Ca* I *Co* I	10	*Fe* I	48	Fe I *Sm* II *Pt* I—*Ti* I *Fe* *Cr* *Ca* I
71	*V* I *Au*—La II Fe I	11	*Fe* *Mn*—Sc I *Cr*	49	**La** II *Tm* Pr—*Eu* *Os* Fe I
72	**Dy** *Rh* I—**Fe** I *Ca* I	12	*Fe* *V* I—Pr	50	*Y* II *Dy*—
73	**Co** I (R)—Fe I **Co** I (R) Dy	13	*Pr* Fe I	51	*Cr* I Fe—*Cr* I *Mn*
74	Tb—*Cr* I	14	*Au* *Fe* I *Ti* I *Zr* II—*Au* I *Dy*	52	Gd *Co* I *Cr* I—*Ce* II *Fe* I *Fe* I *Mn* Co I
75	*V* I (R) *Sm*—*Ca* I	15	Li I Ir—*Dy* Cr I		
76	*Fe* I *V* I *Pr* **Cs** I—*Lu* **Os** I **Co** I *Re* I	16	**La** II Cr I *Tm*—Gd Fe *Cr* I		
77	Pr *Sm*—*Cb*	17	*Co* I Fe I Re I—*Cr* I		
78	**Fe** I—*Os* *Mg* I **Fe** I (R) *Fe* I *Fe* *Co* I (R)				

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
3953	*Fe* I *Cr* I Gd I—Pr *Nd* *Fe*	3990	*Co* I *Fe*—V I *Yb*	4034	*Cr* I Mn I (R)—
55	*Fe* I—*Eu* *Fe*	91	Cr I Zr II—*Co* I *Mn* Cr I *Co* I *Nd*	35	*Sm* II—Co I *Mn* *Ti* I
56	Ti I Fe—Fe I	92	*Cr* Ir I *Ce* II *Mn* *V* I Cr I	36	*Eu*—
57	*Fe* *Ca* I *Nd*—**Gd** *Dy* Co I (R) *Tb*	93	Ba I (R)—*Ce* *Ni* I *Cr* I	37	*La* I *Cr* I Gd—*Os* Gd
58	Tm Ti I Zr II Tb— **Pd** I Rh I	94	*Fe* I—*Co* I *Nd* **Pr**	39	Cr *Pr*—
59	*Sm*	95	*Fe* **Co** I (R)—Tm *Ba* I **La** II *Fe* I	40	*Fe* *Ce* II Ho *Ta* *Au* I
60	*Fe*—*Os* *Pr* *Cr* *Co* I	96	Ta Gd—Tm *Pt* I Dy *Os* *Fe*	41	*Fe* Mn—*Cr* I Os
61	Os *Eu* *Fe* I *Ag*—**Al** I *Zr*	97	Pr **Fe** I—Co I	42	*Cr* I—La II
62	*Fe* *Pr* Re I—*Ti* I *Sm*	98	Fe I—Ti I V I *Cr* *Os*	43	*Cr* *Fe* I
63	*Fe* I—**Os** I *Gd* Cr I	99	*Pr* *Ce* II—*Cr*	44	**K** I—*Fe* I *Pr*
64	*Pr* *Ti* I—*Fe* I Pr *Ru* *Os*	4000	*Pr* *Fe* I *Fe* **Dy**—	45	**Co** I Ho—**Fe** I *Ag* Dy
65	Pr—*Fe* I	01	*Gd* Cr—*Fe* I	46	Hg I *Cr* I
66	*Sm* II *Fe* I *Pt* I—Pr *Fe* I	02	*Tb*	47	**K** I—*Y* I Gd
67	Fe—*Fe* I	03	*Cu* I *Mn* *Os*—*Fe* *Ti* I *Cr*	48	*Mn* *Cr*
68	Ag Zr I **Dy** *Lu* **Ca** II (R)—	04	*Os*—*Fe*	49	*Fe* I *Gd*—*Cr* *Fe* Gd
69	*Cr* I Co I Gd **Fe** I— *Fe* Os Cr I	05	Fe I *Ag*—Tb	50	*Cr* I *La* II—*Cu* I *Fe*
70	Ta *Fe* *Fe*—*Ni* I	06	*Fe*—*Fe* *Fe* I	51	*Pr* *Cr* Ru I—*Fe*
71	Pr *Cr* I Fe I *Sm* II— *Pr* Eu(R) **Eu** I (R)	07	*Fe* I *Sm* II—	52	*Mn*—*Co* I
72	Pr Ni I—Co I *Ca* I *Cr* I	08	*Ti* I—Pr *Fe* *Ti* I	53	*Fe* Gd—Gd I **Ho**
73	Co I—**Ni** I *Fe* Ca I	09	*Gd* *Mo*—*Ti* I Fe I	54	*Gd* I *Fe* I *Pr* *Fe* I
74	Gd *Fe* I—*Ni* I Co I *Fe* I	11	*Fe* I—	55	*Ti* I Zr I *Fe* I **Ag** I (R)—*Mn*
75	*Zr* I *Co* I *Ba* I (R) *Os*—*Fe* *Mn*	12	*Nd* *Ce* I *Cr*—	56	*Mo* *Cr*—Pr *Co* I
76	*Pr*—*Fe* Cr I Tb *Fe* I	13	*Ti* I *Fe* I *Fe* I Fe **Co** I	57	Co I *Fe* I—*Mg* I Zn II **Pb** I (R) *In* *Mn*
77	*Mn* *Co* I Os I—**Fe** I	14	Fe *Cr* *Ce* II	58	*Ti* I Co I *Fe* Gd I— Co I *Fe* I *Cr* *Mn* **Cb** I
78	*Ru* I *Fe* I—Dy Co I *Cr* I *Co* I *Ce*	15	*Ti* I *Pr* La I—	59	*Mn*—*Fe* *Gd*
79	*V* I *Sm* II *Ta* Gd I *Ru* I—Co I *Fe* *Cr* I	16	*Au* II *Fe* I—	60	*Ti* I *La* I—
81	Cr I—*Ag* I Ti I Fe I *Tb* Dy	17	*Fe* I *Fe* I—*Ti* I	61	*Ta*—*Mn*
82	Pr *Ti* I—*Mn* *Y* II *Mn*	18	*Mn* *Cr* I *Os* *Fe* I—	62	*Mo* *Pb* Fe I—**Cu** I Pr
83	Sm II *Cr*—Dy Cr I Fe I	19	*Co* I—	63	*Fe* I *Cu* I—Mn **Fe** I
84	*Ni* I *Mn* *Dy* *Cr* I— *Ru* I	20	*Ir* *Sc* I—**Co** I	64	Zr I *Ti* I—
85	*Mn* Fe—Li I	21	Ti I Fe I	65	*Au* I *Mn* *Ti* I *Fe* I— *Gd* *Cr*
86	Fe I—*Mg* I *Mn*	22	*Cr*—**Cu** I	66	*Fe* Os *Cr* Fe I
87	*Mn* *Co* I Gd—*Gd* Er(R) **Yb**(R)	23	*Sc* I Co I—*La* II Sc I *Cr*	67	*Fe* I La II—*V* I Ta Fe I
88	*Th* *Os*—**La** II *V* I	24	*Fe* I—*Cr* I *Ti* I Fe I	68	*Mn*—Co I
89	*Fe*—Pr Ti I *Fe* *Cr*	25	Cr—*La* II *Mo*	70	*Mn* *Gd*—*Fe* I
		26	Cr *Mn*—*Ti* I	71	**Fe** I
		27	*Co* I *Cr* Zr I—	72	Zr I
		28	*Cr*—	73	*Dy* *Gd* *Cu* I *Fe* II *Ce*— Gd *Fe* I
		29	*Fe* I *Re* I *Ta*	74	*W*—*Os* *Fe* I *Cr*
		30	*Fe* I *Ca* Fe I—Ti I *Cr* **Mn** I (R)	75	*Mn*—*Cu* I *Fe*
		31	*Cr*—*Tb* **La** II *Pr* *Fe*	76	*Cr* *Co* I—*Fe* I *Ru* I *Fe*
		32	*Fe* I **Ga** I (R)	77	*Cr* **La** II *Y* I Co I— *Cr* **Sr** II (R) Hg I Dy(R)
		33	Tb Ta **Mn** I *Cr* I—*Sb* Ir *Pr*	78	*Fe* I Ti I—

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

Principal Lines by Wavelength

Wave-length	Elements
4079	*Mn Mn*—**Cb** I *Pr Fe* I
80	*Fe* I—*Cu* I Ru *Fe*
81	*Pr* Zr I *Mo*—*Cr Pr*
82	*Fe* I *Ti* I—*Co* I Rh I *Mn*
83	*Fe* I *Mn Y* I *Fe* I
84	*Au* I *Sm* II Fe I—
85	*Fe* I *Cr* Fe I—Gd
86	**Co** I—**La** II
87	*Fe* I *Pr* **Pd** I—*Gd*
88	*Co* I Os—*Fe*
89	*Fe* I—*Yb Mn*
90	*Cr Co* I Gd I—*V* I
91	*Fe* I Os
92	*Cr Fe Mn* **Co** I—*Ir* *Ca* I Gd I *Co* I
94	**Tm**—*Ca* I *Pr*
95	*Fe* I
97	*Cr* I *Cr* I
98	*Cr* I Fe I—*Ca* I Gd
99	*Cr*—La II
4100	Ir *Fe Os*—*Fe* I Pr *Tb* **Cb** I
01	*Cr Fe* I—*Fe* I **In** I (R)
02	Y I—Mn
03	*Dy*—Ho
04	*Fe* I *Cu* I *Co* I—*Co* I *Cr*
05	*Mn*—**Tm**
06	*Fe* I *Fe* I—Sm II
07	Fe I—*Mn*
08	*Hg* I *Cr* I—Ho
09	*Fe* I—*Cr* I Fe I
10	**Co** I *Mn*(R) *Cr* I
11	*Cr* I—*Cr* I V I (R)
12	Os *Fe* I—*Ti* I Ru I *Fe*
13	*Mn*—*Mn*
14	*Mn Fe* I—*Fe*
15	Ir
17	*Ir Fe* I
18	Pr—*Sm* II Fe Pt I Co I (R)
19	Rh I
20	*Ho Fe*—*Cr* I
21	*Cr* **Co** I (R)—Bi I *Re* I Rh I *Cu* I *Fe* I *Cr*
22	*Cr* I—*Fe* I
23	*Na* II *Ta* (R) **La** II *Cu* I *Cr*—*Fe* Cb I
4124	Lu
25	*Fe Fe* I
26	*Fe* I—Cr I *Fe* I *Cr*
27	Ho *Cr* I—*Ti* I Fe I *Cr* I *Fe*
28	*Mo* Y I—**Rh** I *Os*
29	*Fe* Ta—Eu II (R)
30	*Fe* I Gd—*Ba* II (R)
31	*Mn Cr Gd*—
32	**Fe** I **Li** I *Ba*—
33	Re I—*Fe* I
34	*Cr Fe* I—Fe I
35	*Mn* **Rh** I—Os
36	*Ta* Re I—
37	Fe Cb I *Mn Ti* I—Os
38	*Tm*—
39	*Cb Fe* I
40	Pd I (R)
41	*Mn* Pr—La II *Fe* I
42	*Cr*—Y I
43	Pr Fe I—Mo **Fe** I
44	Ru I Re I *Tb*—
45	Ru I
46	*Fe* I *Cr Cr* II—*Cr* Ru I
47	*Mn* Fe I
48	*Ru* I—*Mn*
49	Zr II Fe I—
50	*Fe* I—
51	La II
52	*Fe* I—Cb *Cr*
53	*Cr* I—*Cr* I Fe I
54	*Rh*—Fe I Fe I
55	*Mn Ir*
56	Fe I
57	*Mn*—Fe I
58	*Co*—*Os* Fe I
59	*Ti* I
61	*Fe* I *Cr Fe*—
62	*Gd*
63	Ho—Cr *Cb Fe* I
64	Pr—Pt I
65	*Fe*—*Cr*
66	*Ba* II Ir *Zr* I—
67	*Y* I Ru I *Fe Fe Dy*
68	*Pb* Cb—*Fe*
69	*Cr*Pd I
70	*Gd Cr*—*Fe* I
71	*Cr Fe Pr*
72	**Ga** I (R) *Fe Pr*—Ir I *Os Fe* I *Cr*
4173	*Ho* Os *Fe* I *Fe* II—*Fe* I
74	Y I—Cr I Fe I
75	Ta *Cr*—*Gd* Os Fe I *Cr*
76	Fe I Mn
77	*Y* II Fe I *Cu* I *Cr*
78	*Fe* II *Tb*
79	Cr Pr—*Cr*
80	Ti I
81	Fe I
82	*Fe* I *Ir*—Re I (R)
84	Lu Gd—Fe I *Cr*
85	*Cr*—
86	Ti I *Cr*—*Ce* II Dy
87	Fe I *Co* I *La* I—**Tm** Fe I
88	Mo—
89	Pr *Os Mn*
90	*Cr* Gd—Gd I
91	Gd *Cr* I *Fe* I—*Fe* I *Cr* I
92	*Cr La* II Pt I—
93	Cr
94	*Dy Cr*
95	Os Fe I—*Ni* I *Fe* I
96	Fe I—Rh I La II *Ru*
97	*Cr*—Ru I
98	*Na* I Fe I—Cr *Fe* I *Ru* I
99	**Fe** I—Ru I Tm
4200	*Cr Ni* I—*Fe* I
01	*Zr* I—*Ni* I *Mn* **Rb** I (R)
02	**Fe** I Os—*Fe*
03	*Ti* I—*Fe* I Cr I Tm Fe I
04	La II *Cr* I *Cr*—
05	Eu II (R)—*Fe* I Ta
06	Ru I *Ta*—Fe I *Pr Cr*
07	*Fe* I—
08	Cr—Fe
09	Cr—*Cr*
10	*Sm* II **Fe** I—Ag I
11	Cr—Dy *Mn* Os Pr
12	Gd Ru I—*Cr* I Ag I **Pd** I
13	*Cr*—Fe
14	Ru—
15	Gd *Dy Fe* I—**Sr** II (R) **Rb** I (R)
16	Fe I *Cr* I—

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
4217	Gd Ru I—La II Fe I Cr I *Cb*	4263	Ti Cr—La II *Pr*	4308	*Bi* I—Dy
18	*Dy*—	64	*Fe* I *Ba* I—*Fe* I	09	Sm II *Fe* Fe I—*Y* II
19	Fe I—	65	*Sm* II *Ir* I—Mn	10	Ir Gd
20	*Fe*—*Mn* Sm II *Ru* I	66	*Gd Cr Fe* I	11	Pr Os **Ir**—
21	Re I *Dy*—*Cr*	67	Fe	12	*Cr*—Mn
22	**P** Fe I—*Ce* Cr I Pr	68	Ir I *Ta*—*Fe Cr*	13	Gd
23	*Sm* II	69	La II—*Cr*	14	*Sc* II Gd—Ti I
24	Fe I—*Cr Fe* I	70	*Ti* I—	15	**Fe I** *Au* I—*La* II
25	*Pr Fe* I—Gd *Fe* I	71	*Cr* **Fe** I—**Fe I**	16	*Pr* Gd—
26	*Fe* I *Tb*—Ge I **Ca** I (R) *Ce* Cr	72	*Pr*—*Cr* I	18	Ti I *Ca* I Tb **Sm** II
27	*Gd* **Fe** I Re I—Zr I	73	Li I (R)—	19	*Sr* I—*Sm* Cr I
29	*Cb*—*Fe* I	74	Gd—Ti I **Cr** I (R)	20	*Gd* Cr I *Ce* II *Sc* II
30	*Ru* I *Cr* I—La II	75	*Cu* I—*Cr*	21	*Gd Mn Cr*—*Cr Ti* I *Fe*
32	*Cr*—Mo *Fe* I *Cr* I	76	*Ti* I—*Fe* I *Tb*	22	*Gd*—La II *Eu*
33	Fe II—Fe I Co I	77	*Cr*	23	Sm II *Mn*—Cr Pr
34	*Cr Sm* II	78	*Ti* I—Tb	24	Gd—
35	*Mn Mn*—**Eu** (R) **Fe** I *Y* I	79	*Fe* I—Sm II *Sm* II	25	*Sc* II Cr Ti I *Ba*— *Ni* I Gd I (R) **Fe** I Nd Tb
36	*Sm* II	80	*Pr La* I *Cr*—Gd Sm II	26	*Mo Ti* I Tb—*Mo Mn* *Fe* I
37	*Fe*—*Sm* II *Cr* I	81	*Sm* Mn *Ti* I—	27	*Pt* I Fe **Gd**(R)—
38	*Fe* I **La** II—Gd Fe I Cr I	82	**Fe** I *Pr*—*Ti* I	28	*Pr*—*Os Pr*
39	Zr I—*Ba* I Mn *Fe* *Fe* I	83	*Ca* I *Ba*—	29	**Sm** II Eu *Pr*—Gd Eu
40	Zr I *Fe Ca* I—Cr	84	*Mn*—Mo *Ni* I *Cr* I	30	*Sm Fe Pr Ce* II—Gd *Fe*
41	*Pr* Ru I Zr I—Zr I *Au* I	85	Fe Sm II—Co I *Gd*	31	*Eu*—Ni I
42	**Tm** *Cu* I—*Ba*	86	Ti I *Gd Ta*—Ir Sm II **La** II *Fe* I	32	*Re* I—Cr *V* I *Ba* I
43	Ru *Fe*—*Gd*	87	Ti I—	33	**La** II Pr
44	Sm II	88	Ni I *Pt* I *Fe* I—*Mo* **Rh** I *Fe* I	34	*Sm* II—
45	*Fe* I—	89	Ti I *Ca* I—**Cr** I (R) *Ce*	35	*Pr*
46	*Fe*—Gd *Sc* II *P*	90	*Fe*—*Fe* I *Ti* I	36	Sm—
47	*Nd* Fe I—*Pr*	91	Re Fe I—*Cr*	37	**Fe** I *Mn*—*Gd* **Cr** I Eu Sr I *Ti* II
48	Fe I *Cr* I—*Ce Cr Cu* I	92	Mo Sm II *Fe* I—*Zn* I	38	*Cr* Tb—Pr *Cr*
49	*Ti* I—*Sm* II La II	93	Mo—*Cr* I *Os* I	39	Hg I **Cr** I (R)—*Co* I Cr I
50	Fe I—**Fe** I	94	*Ti* II **Fe** I—*W* I	40	*Cr* I—*La* I
51	**Gd** Sm II *Mo*	95	Ti I Cr I Ni I	41	*V* I *Zr* I Gd—*U*
52	*Cr* I Co I—	96	La II Gd—Sm	42	*Ru* I Gd—*Tb V* I
53	*Gd*—*Gd*	97	Cr I Gd—*Ru* I Cr *Pr*	43	*Cr* I *Fe*—*Hg* I *Fe*
54	**Cr** I (R) Ho—	98	Fe I *Zn* I—Ti I *Ca* I	44	Pr—**Cr** I
55	*Fe*—*Cr*	99	*Ti* I **Fe** I—*Ti* I Cr I	45	*Cr*—Sm II Eu
56	*Ti* I *Zr* I Sm II— *La* I	4300	*Mn*—Cr Ti I	46	Gd—*Fe Gd* Cr
57	*Cr* I—Re I Mn	01	Ti I Cr—Ir	47	Gd Pr Hg I—*Cr* Sm II
58	*Fe* I—*Ti* I *Sm* II *Fe* I *Fe* I	02	*Pr W* I *Fe* I—*Ca* I *Cr* Zr I Ta	48	*W* II—Y I
59	Ir *Cr* I *Cu* I—	03	*Fe* II—Nd Pr	50	*Mo Ba Pr* Sm II—
60	*Fe* I *Fe* I **Fe** I—Os I	04	Gd Sm II	51	Cr I *Ir*—*Fe* I *Fe* II **Cr** I *Pr Mg* I
61	*Mn* Cr I—*Ti* I *Cr*	05	*Sr* I Cr I Fe I—*Mn* Pr Ti I	52	Sm—*Ir* **Fe** I
62	Gd *Cr Cr*—Sm II	06	Gd—	53	*Tb*—*Cr*
		07	*Cr*—*Ca* I Ti II **Fe** I (R)	54	*La* II—*Sc* II Eu *Pr*

Intensity (**Ba** above 300, Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
4355	*Ca* I Eu I *Ta*—	4400	*Fe* Sc II—*V* I *Nd*	4453	*Mn* Ti I—*Ti* I
56	*Tb*	01	*Sm Fe* I *Fe* I—**Ni** I Gd	54	*Pr* **Fe** I—Sm II Re Ca I
58	*Nd* **Hg** I—*Fe* I *Re* I *Y* II	02	Ta—*Ba Os*	55	*Mn Fe* I *Mn* Ti I—*Mn* Ca I
59	*Pr*—*Ba* Ni I Cr I Pr *Cb* **Tm**	03	Gd *Sm* II—Pr **Ir**	56	*Ca* I
60	*Ti* I—Sm II Gd	04	*Ti* I—**Fe** I	57	*Mn Mo* Ti I—
62	Sm II—*Sm Pr*	05	Pr *Re*—*Gd Ba Sr*	58	*Fe* I *Mn Pr*—Sm II *Cr* I
63	*Cr Sm* II—	07	Fe I *Be* I	59	**Ni** I **Fe** I—*Cr* I
64	*La* II	08	*Mn* Gd Fe I—Pr	60	Ru I *Ce Mn*—*Cr* I
65	*Mn*—*Os*	09	Sm II—	61	*Mn Fe* I—**Fe** I
67	*Re* Fe I Fe I	10	Ru I *Cr* I *Mn*—*Ni* I *Fe*	62	*Mn* Ni I—*Cr* I *Nd*
68	*Sm* II Pr—*Nd Mn*	11	*Nd* Gd—Mn	64	*Mn Fe* I *Eu*
69	*Gd*—Fe I Gd	12	*Pr Cr* I—	65	*Cr* I—Ti I *Pr*
70	*Eu*—*Os*	13	*Ba Pr Cr*	66	Gd **Fe** I **Co** I *Fe*
71	*Co* I Cr I—Pr	14	Gd *Cr* I—Gd Mn	67	*Gd Ba* Sm II—*Cr* I *Re*
72	Ru I—	15	**Fe** I—Sc II *Cu*	68	*Ti* II—Pr
73	*Rh* I *Cr* I *Sm* II—*Fe* I Gd	16	*Ti* I	69	Fe I—Co I
74	*Cr Pr* Sc II—*Ca* **Rh** I Y II Mn Sm II	17	*Eu Ti* I—*Sm* II	70	*Mn Ni Sm*
75	*Cr*—**Fe** I	19	Gd *Pr*—*Fe* Pr Mn	71	Ti I *Gd*—Co I
76	*Fe* I *Cr*	20	**Os** I—Sm II	72	*U* Sm II—*Fe* Mn
77	Ir—*Cr*	21	Sm II Pr Gd *Ru* I—*Ti* I	73	Sm II—*Pd* I *Cr* I Ru I
78	Cu I Sm II—	22	Gd—**Fe** I *Y* I *Ti* I	74	Gd—Mo *Mo Ti* I
79	V I (R) Pr *Bi* II—*Rh* I	24	*Cr* I **Sm** II *Nd*—*Pr*	75	*Cr* I—
80	*Pr*—Gd	25	Ca I—	76	**Fe** I *Fe* Gd—
81	*Cr* I—Mo *Mn*	26	*Ti* I *Gd* **Ir**—	77	*Cr* I *Co* I Pr—
82	*Mn Fe*	27	Ti I **Fe** I—	78	Co I Ir—Sm Gd
83	Eu I—**Fe** I	28	Ru I—*Cr* I	79	*Mn*—*Fe* I *Ti* I *Os*
84	*Sm* II—*Ni* I *Fe* I V I (R) Cr I	29	Pr—La II	80	*Fe* I Cu I *Ru*—Ta
85	Ru I—Ru I	30	*Fe* I—Fe I Gd	81	*Gd* Ti I **Tm** Mg II—
86	*Ta* Tm—	31	*Sc* II—*Gd Ba*	82	Fe I Fe I—*Fe* I *Cr*
87	Gd Eu Fe I	32	*Cr* Pr—*Fe*	83	*Gd*—*Co* I Co I
88	*Mn* Fe I—	33	Fe I—Sm II	84	Fe I—*Co* I Os
89	*Fe* I—*Mn* V I (R)	34	Ti I Sm II—*Mo* Ca I	85	*Fe* I
90	*Na* I Ru I (R)—*Mg* II Sm II Fe I Gd	35	*Fe* I—**Eu Eu** Ca I	86	*Co* I Gd
91	*Th Re*—*Cr* I *Pt* I	36	*Os Mn*—*Fe* I	88	*Cr Fe* I *Au* I—*Os V* I *Ba* I
92	Gd Re—Ir	37	*Au* I—	89	Ti I *Cr*—Fe I
93	*Na* I—*Ti* I	38	*Pr Fe* I—	90	Mn *Fe* I—*Fe* I
94	Re(R)—Os	39	Ru I *Fe* I	91	*Mn Cr* I *Cr*
95	*Ti* II *V* I (R) *Fe* I—*Ag*	40	*Ti* I—	92	*Cr*—
96	*Pr* Ag—	41	*Ta*—Ta	93	Tb—*Ba* I
97	*Cr* I—Gd Ru I	42	**Fe** I—**Pt** I	94	*Na* I—**Fe** I Co I *Ta*
98	Y II—	43	Fe I—*Ti* II	95	Ir—
99	Ir—*Cr* I	44	Sm—	96	*Ti* I Pr Ta—*Mn* Cr I
		45	Co I	97	Gd—*Na* I
		46	Nd *Gd*—*Fe* I *Pr*	98	Ru I Gd—*Cr* Pt I Mn
		47	*Mn* Os—Fe I	99	Sm II
		49	Ti I *Ce* Ru I—Pr	4500	*Cr*—
		50	*Ir*—Ti I	01	*Cr Ti* II—*Nd*
		51	Nd Mn *Pr Nd*		
		52	Sm II		

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
4502	Mn—	4548	*Gd* Ir—*Pr Mn* Os Ti I	4600	*Cr* Ni I—Cr I
03	*Mn*	49	Fe II—Ti II **Co** I	01	*Ta*—
05	*Ba Y* I	50	Os—*Ir Fe*	02	*Fe* I Ta—**Li** I **Fe** I
06	Gd *Gd*—*Nd Cr Gd*	51	Os—**Ta**	04	*Sm* II—Ta *Ba* **Ni** I
07	*Cu* I	52	*Pr Pt* I *Co* Ti—*Fe* *Sm* II	05	Mn—*Re* La II *Cr*
08	*Fe* I—	53	*Co* I—Ta *Cr*	06	Ni I—*Cb*
09	*Ta* Cu I—	54	**Ba** II (R) *Sm* II—Ru I (R) *Cr*	07	**Sr** I (R) *Au* I—*Mn* *Fe* I
10	Pr—Ta	55	**Cs** I (R) Ti I—	09	*W Mn*
11	Sn **In** I (R)—**Ta** *Nd* Sm II *Cr*	56	Fe I *Cr* Ta—	11	*Sm* Fe I—*Eu*
12	*Ca* I—Ti I	58	La II—*Cr* II	12	*Pr Dy*—
13	**Re**—	59	La II—*Ti* I	13	*Fe* I *W* Cr I La II—
14	*Co* I—*Gd Cr* I	60	*Fe* I *Nd Sm* II *Mn*—	14	*Co* I—*Gd Re*
15	Sm *Fe* II *Cr*—	61	*Tm Co* I	15	*Sm* II Tm
16	*Re* Ru I	63	Pr *Nd*—*Tb* Ti II	16	**Cr** I (R) Ir—Os
17	**Co** I—*Fe* I *Ru* I	64	*Co*—	17	Ti I—*Fe* I
18	Ti I—**Lu**	65	*Fe*—*Cr* I **Co** I *Fe* I Ta	19	Fe I *Mn*—Ta *Cr* La II *Ba* I
19	*Co* I—*Tm* Sm II Gd Ni I	66	Sm II—*Fe* Co I Ta	20	*Co* I *Hf*
20	*Gd Fe* II—	67	La I	21	*Cr Cr*
21	Ta *Cr*—	68	Ir—*Fe* I	22	*Cr*—*Co* I *Cr Ta*
22	La II—*Sm* Tm **Eu** Eu I (R) *Fe* II Re Ti I *Gd*	69	Rh I—*Cr*	23	Co I Ti I—
23	*Ba Mn*—Sm II	70	*Ir* **Co** I *La* I—	25	Fe I *Eu Mn*—Co I
24	**Sm** I *Cr Os Ba* II	71	*Mg* I *Mn*—*Cr* Ti II	26	Cr I *Tm* Mo—*Mn Tm*
25	Fe I La II—	72	*Be* I *Mn*	27	*Eu Mo*—*Mn*
26	*Cr* La II *Fe Cr* I—Eu Ca I	73	Ta—*Ba*	28	*Ba*—Pr Co I
27	*Ce* Ti I Ta—Co I	74	**Ta**—*Fe* I **La** II *Co* I	29	*Fe* II *Ti* I **Co** I—*Zn* I
28	**Fe** I **Rh** I (R)	75	*Cr Mn*—*Zr* I	30	*Fe* I—*Re*
29	*Tm*—*Fe* I *Os Fe Mn*	76	*Yb Pr*—	31	Os
30	Cr I Cu I **Ta** *Ru* I Co I	77	Sm II	32	*Cr*—*Fe* I
31	Fe I—*Fe* I	78	*Cr*—*Ca* I Tb	33	Ta *Cr* I—
32	*Sm*—*Ir*	79	*Co* I—*Ba Mn*	34	*Nd Tm*—
33	Ti I—Co I	80	**Cr** I *La* II **Co** I—Ta	35	Ru I
34	Pr *Mn*—Ti I	81	Ca I—*Fe* I **Co** I Mn	36	*Ba*—
35	*Cr* I—*Ti* I Cr I Pr	82	*Yb*—*Mn*	37	*Cr*—Fe I *Cr*
37	*Os* Gd *Sm* II	83	Ta—Fe II	38	*Fe* I—
38	*Mn*—	84	*Cr* Ru I (R)—*Sm* II *Mn*	39	*Ti* I—*Pr Ti* I
39	Cu I *Cr* I Os	85	Ca I	41	*Nd*—
40	*Gd*—*Cr Co* I *Hf*	86	*Mn Cr*—*Nd* Cu I	42	Sm II—*Mn*
41	*Cr* I *Nd*—*Cr Na* I	87	*Cr* I—Co I	43	*Fe* I—*Pr Y* I
42	*Gd Sm Nd Mn*—*Nd* *Cr*	89	*Dy*—	44	*Eu Co* I—
43	*U Cr* **Co** I Sm II	91	*Ru* I Cr II—Sm II *Ba*	45	*Mn* Ru Ti I *Tb*—
44	*Mn*—Cr I Ti I	92	Ru I Ni I *Cr* Fe I	46	*Pr* Cr I *Nd*—*Sm* II *Nd Cr* I
45	*Na* I *Co* I *Cr* I—Ir Cr I	93	**Cs** I (R)—*Sm* II *Th*	47	Fe I—Ru
46	*Ni* I	94	**Eu**(R)—Co I	48	*Cr*—Ni I *Cr Cb*
47	Ta *Ni* I—Fe	95	*Os* Sm II *Fe*—*Cr*	49	*Cr*—
		96	*Fe* I—**Co** I	50	*Ti* I—
		97	Os—	51	Cu I Cr I—Pr
		98	*Fe* I *Cr*—	52	Cr I (R)—
		99	*Tm* Ru I—*Ba W*	54	Ru I—*Fe* I *Fe* I *Cr* I *Co* I

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

Principal Lines by Wavelength

Wave-length	Elements
4655	*Hf* La II—*Ni* I
56	*Ir Cr* Ti I—*Eu*
57	Co I *W*—
58	Lu—*Mn*
59	W
60	*Eu*—
61	**Ta**—*Eu*(R) Eu
62	La II
63	*Cr* I **Co** I—*Sm* La II Os *Cr* I
64	*Hf* I—Pr *Cr* I *Na* I
65	*Cr*
66	*Cr*—*Cr* I *Ni* I
67	Fe I—Ti I Ni I
68	Fe I Ag I—Na I La II (R)
69	**Ta** *Fe* I *Cr* I—*Sm* II
70	Sc II *V* I (R)—
71	Mn La II
72	Pr Cb—
73	*Fe* I—*Ba*
74	*Sm* II *Nd* Cu II *Y* I
75	Rh I *Ti* I *Cb*—
76	Sm II
77	*Tm*
78	Cd I—Fe I
80	*Gd* **Zn** I *Fe* I—W *Cr* I *Nd Cr*
81	*Sm* Ru I Ta Ti I *Tm*
82	*Y* II **Co** I—
83	Gd *Nd*—*Fe* I
84	Ru I—*Cr* Ta Pr
85	*Eu Ca* I *Ta*—*Co* I
86	*Cr* Ni I—
87	Sm II—Zr I *Pr*
88	Eu *Zr* I—*Sm*
89	*Cr* I—
90	*Fe* I—
91	Ti I *Fe* I—Ba **Ta**
92	*Os*—La II *Eu*
93	**Co** I Ta—*Sm* II *W Cr*
94	*Gd*—
95	*Cr*—*Pr*
97	*Cr* I Gd *Cu* I—
98	**Eu Co** I **Ni** I **Cr** I— *Cr* I Ti I
99	*Co* I *Sm* II—*Cr* La II (R)
4700	*W Ba* I—*Cr* I
01	Mn Ta Ni I—Ni I
02	*Gd Tb*—
4703	*Gd* La II (R)—Ni I
04	Sm II—Cu I
06	Ta *Cr Cb*—*Nd*
07	Mo Fe I—*Pr Pr*
08	Cr I *Pr Cb*—*Fe*
09	*Fe* Ru I—Mn Gd
10	*Zr* I Ti I *Fe* I—*Sm* II
12	La II (R)
13	Sm II—Eu
14	*Fe* **Ni** I—*Sm* II
15	Sm II—Ni I
16	Sm La II—
17	*Sm Eu*—*Cr* Sm II *Mo*
18	Sm II Cr I *Co* I—*Eu*
19	*Nd Gd*—Sm II La II (R)
22	**Zn** I—**Bi** I *Ti* I **Ta**
23	Cr—Gd
24	Cr—
26	Sm II *Ba* I—
27	*Cr Fe* I—**Co** I
28	**La** II (R) Sm Gd— *Y* I *Fe* I *Sc* I Ir
29	Sc I—*Fe* I *Cr*
30	Ta—*Pr* Cr
31	*Ru* I Mo *Fe* II—Ni I
32	Ni I—
33	*Tm*—*Fe* I
34	Sc I Pr Gd—Co I
35	Gd *Fe*
36	*Eu* Pr Fe I
37	Cr—Sc I Co
38	Gd—
39	Mn *Eu* Zr I—
40	Ta(R) La II—**Eu**
41	Sc I—*Fe* I *Sm* II
42	Ti I
43	La II (R) *Cr*—**Gd** Sc I *Os*
44	*Pr*—Pr
45	*Cr* I—Sm II *Fe* I
46	Co I—Pr
47	*Fe*—
48	*Na* I *Re*—La II
49	Co I Cb
50	*Sm*
51	*Na* I
52	Cr *Ni* I Ni I—Tb
53	*Sc* I—
54	**Mn** Co I—*Cr* Ni I
55	*Cr* I Sm II—*Eu Pr*
56	Cr *Pr*—Ta Ni I Co I
4757	*Cr*—*W* Ru I Pr
58	Ti I—*Eu*
59	Ti I—
60	Mo Sm—*Y* I
61	*Cr*—*Mn*
62	Mn—Ni I *Pr Eu*
63	Ni I
64	Cr *Mo*—*Cr* I
65	*Pr*—*Mn*
66	*Mn*—*Cr* I La I
67	Co I *Gd*—Cr
68	**Co** I *Fe*—Ta
70	*Cr* I
71	**Co** I—
72	Zr I—*Fe* I
74	*Mn* Sm II—*Cr* I
75	*Cr*—
76	**Co** I—
77	Sm II
78	*Ir* Co I—
79	*Sc* I—
80	**Co** I—*Ta*
81	**Co** I—*Sm* II *Yb* Gd
83	*Cr* Sm Pr **Mn**—
84	Gd
85	*Co* I Lu—Sm
86	**Ni** I *Yb* Fe I
88	Pd I—*Fe* I
89	Cr I Fe I *Sm*
90	Cr I—
91	Fe I Re—Sm II Gd
92	*Ti* I—Cr Au I Co I
93	*Os*
95	Co I
96	Cr Co I—
97	*Mn Cr*
98	Sm II (R)
99	*Ti* I **Cd** I *W*
4800	*Fe*
01	Cr Gd—
02	Gd
03	Gd
04	La II—*Cr* I
05	*Ti* I—Gd
06	*Cr* I—Ni I
07	Gd—
08	*Mn Ni* I
09	La II—
10	**Zn** I Cb *Cr*
11	*Mo Nd*—*Au* I
12	Ta

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
4813	Co I—Co I	4875	Gd Sr—	4938	Sm II Fe I *Ti* I Eu *Ru* I—Gd **Fe** I
14	Cr—	77	*Ba* I *Pr*	39	*Fe* I—Fe I Pr
15	Sm II *Os*	78	Ca I *Fe* I—	40	*Pr*—
16	*Cr Cb*—*Gd*	80	*Cr*—	42	Cr I—Gd
19	*Mo*—Ta	81	*Gd Gd*—Gd	44	*Cr Nd*
20	Ti I—	82	Gd—*Sm Nd* Ta *Sm*	45	*Ni* I—
21	Fe *Ni* I—Gd	84	*Cr* I	46	*Sm Fe* I La II—Re
22	Pr	85	Ti I—*Cr* I	48	Sm II
23	**Mn** *Cr*	86	*Fe* I—*W Ni* I	49	La I
24	La II—	87	Cr—	50	*Mo*
25	Ta Nd—*Mn*	88	Cr I	51	Pr—
29	**Ni** I **Cr** I—Sm II	89	**Re** I *Gd*—	52	*La* II Sm II—*Fe* I
30	Mo	90	Fe I	53	*Sm* II *Co* I Ni I—
31	Ni I *Tm*—*Cr*	91	*Fe* I—	54	*Nd* Cr
32	Pr Sr I Ta—*Ni* I *Fe*	93	Sm II—	57	*Tm* Fe I—*Mo* **Fe** I
33	*Sm* II—	94	*Sm* II Gd *Cr*—	58	Gd
34	Gd—Sm II	96	*Nd*	61	Gd—Sm II
35	Gd—	99	*Os*—**Co** I Ti I **La** II *Ba* II	62	*Al* II—*Fe*
36	*Sm* II *Cr* I	4900	Sm II	63	Rh I
37	*Pr*—Sm II	01	*La* I	64	*Sm* II
38	*Mn*—Ni I	03	*Ru* I Cr I **Fe** I—*Mo*	65	Gd Cb—*Mn*
39	*Mo Lu*	04	*Co* I **Ni** I—*Ta Lu Sm*	66	**Fe** I—Co I
40	*Mn* Co I—Ti I	05	*Cr Fe* I—	67	Cb
41	Sm	06	*Pr*	68	*Ta*
42	*Rh* I—	07	*Ta Fe* I	69	Gd—*Fe*
43	*Ni* I **Co** I—*W* Rh	09	*Fe* I—	70	La II *Fe*—
44	Sm II *Mn*—	10	Fe I Sm—*Fe* I	71	Ni I—Co I **Li** I
46	Ta—	11	*Fe* I	72	*Sm* II—
47	Sm II	12	Ni I—*Os*	73	Fe I—
48	*Gd* Sm Cb *Ti* I—Pr	13	Sm II *Nd*—Ti I Ni I	75	*Ti* I—*Sm*
51	*Rh*	14	*Pr*—*Ta*	77	*Mo*
52	*Ta*—Ni I	18	Ni I—Sm **Fe** I	78	*Ti* I—*Na* I *Fe* I
54	Sm II—*Mn* Y II	19	*Th*	79	Mo—*Co* I
55	*Cr* I **Ni** I—*Fe* I	20	Ta Sm II—**Fe** I *Nd* *Cr* **La** II	80	**Ni** I *Ru* I—
56	Ti I *Gd*—*Gd*	21	*Ta*—Ti I **La** II	81	*Sm* II **Ti** I
57	*Cr* I Ni I—	22	Cr—	82	Fe Na I
59	*Nd Gd*—*Sm* II Fe I *Y* I	23	*Ta*—*Fe Fe* II Re	83	Fe I—Fe I
60	La II	24	*Nd Pr* Fe I	84	**Ni** I—
61	*Cr* I—Gd Cr	25	Ni I	85	Fe I—Fe I *Cr*
62	*Mn*—Gd	26	*Ta*—	86	La II
64	*Ni* I—**Gd**	27	*Fe*—*Fe*	88	Co I (R)—Fe I Cb
65	*Os*	28	Co I Ti I—	89	Ti I *Pr Sm* II—
66	**Ni** I Gd—	30	*Cr Fe* I—*Gd*	90	*Fe*—
67	Co I	33	*Fe*—	91	Ti I *Fe* I La II—
68	*Mo* Ti I—	34	*Fe* I *Co* **Ba** II *Mn*— La II	92	*Sm* II—
69	Ru I—Sm II	35	Yb Ni I	93	*La* I
70	Gd Ti I—Cr Ni I	36	*Pr Sm* II Cr Ta—	94	Lu Fe I—
71	Fe I—Gd *Ta*	37	**Ni** I—	96	Ni I
72	Fe I—			97	*Ti* I—*Fe*
73	Gd Ni I—			98	Ni I—
74	*Ag*—*Cr Ni* I			99	**La** II—Ti I *Mo*

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100.) (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
5000	Ni I—	5058	*Cb Ni* I—	5122	*Cr* I *Sm*—Co I La II
01	*Ti* I Lu—**Fe I**	59	*Pt*—	23	Fe I
02	*V* I—*Fe* I	64	*V*—*Au* I Ti I	24	*Co* I *Eu Sm*
03	*Ni* I	65	*Fe* I *Fe Cb*—*Cr* I *Ti* I	25	Fe I *Ni* I—*Gd* Co I
04	*Mn Fe*	67	*Cr* I *Ta*	26	Co I *Fe* I—*Re*
05	Fe	68	*Cr*—**Fe I**	27	Fe I—
06	**Fe I**—	69	*W* Sm II—	28	*V* I
07	Ti I *Fe* I—	71	Sm—	29	Eu *Ni* I—Pr
09	*Ti* I *Tm*	72	*Cr* I	31	Fe I—
10	*Ni* I—*Gd Fe Ni* I	74	Yb—*Fe* I	33	*Pr Co* I Eu—Fe I
11	*Fe*—	76	*Ta*—*Yb*	34	Cb
12	**Fe I** *Ni* I—*Ta*	78	**Cb** *Fe* I	35	Lu *Pr*—
13	Eu *Ti* I *Cr* I—	79	Fe I—Fe I *Ni* I	36	*Ta*—Ru I
14	*Ni* I Ti I—V I **Fe I**	80	Ni I	37	Ni I Fe I—
15	Gd—	81	Ni I—Sc I	38	*V* I—
16	Ti I—*Sm* II *Cu* I	82	Ni I—	39	*Ni* I Fe I Fe I— *V* I *Cr*
17	*Th*—Ni I *Cb*	83	Fe I—Sc I	41	Fe I
18	*Ni* I *Fe* II—*Pr*	84	**Ni I**—	42	Fe I Ni I Fe I
19	*Pr*	85	*Sc* I **Cd I**	44	*Cr* I
20	Ti I—	86	*Sc* I	45	*Fe* I La I Ti I—*Co* I
21	*Ca*—*Cr* I	87	*Ti* I *Ta Y* II	46	Ni I—**Co I**
22	Fe I—Ti I Eu	88	*Ni* I *Ni* I	47	*Ru* I *Au* I *Ti* I—
23	*Fe*—*Sm* II	90	Rh I *Ta Fe* I	48	*Fe* I *Fe* I—*V* I
24	Ti I	91	*Cr* I	49	**Na I**—*Os* Co I
25	Ti I	93	*Ru*	50	Fe I *Mn*
26	*Cb*—*Pr*	94	*Ni* I—Co I	51	*Fe* I
27	*Fe* I *Fe*—	95	*Cb*—	52	*Ti* I—Cb
28	Fe Sm II—	96	Re *Ni* I *Fe* I	53	**Cu I**—**Na I**
29	**Eu**—	97	*K* I—	54	Co I Sm—
31	*Sc* II—	98	Fe I	55	Sm II Ru I *Ni* I— Rh I *Ni* I
33	*Eu*	99	*K* I Sc I (R) *Ni* I— Ni I	56	*Sr* I **Co I**—*Ta*
34	Tm—	5100	Cb *Sm* II—	58	*Co* I—*Rh La* I *Co* I
35	**Ni I**—Ti I *Ni* I	02	*Fe* I—*Ni* I	59	*Fe* I—*Ba*
36	*Sm* Ti I—	03	Sm II—	60	Eu Cb—
37	*Ta*—	04	Sm II—*Re*	61	*Ta*
38	Ti I—*Ni* I	05	**Cu I**	62	**Fe I**—
39	Cb *Os Ni* I Fe I—Ti I	06	La I *Fe*—	63	**Pd I**
40	Hf II	07	Fe I—	64	Cb—*Fe*
41	*Ni* I Fe I—*Ca* I **Fe I**	08	Co I	65	*Co* I *Fe* I—
42	*Er Ni* I—	10	*Pr* **Fe I**—*Cr* I Pd I Pd I	66	Sm II Fe I—**Eu**
43	*Ta*—	11	*Cu* I	67	Mg I **Fe I**—
44	*Pt Fe* I Sm—	12	*K* I Sm II—	68	*Ni* I *Fe* I—*Sm*
46	*La* I	13	*Cr* I Co I *Ti* I—	71	Ru I—**Fe I**
48	*Ni* I *Fe* I—*Cr* I *Ni* I	14	Eu—La II	72	Mg I *Sm Mo*
49	**Fe I**	15	*Ni* I—*Ta*	73	Ti I Pr
50	*La* I *Gd*	16	Sm II	74	*Mo*—
51	*Ni* I Fe I *Cr* I	17	*Pd* I *Sm*—*Mn*	75	*Sm*—*Ba* Rh
52	Sm II *Ti* I	20	*Cb* Ti I—	76	**Co I** (R)—*Ni* I *V*
53	*W*—	21	*Ni* I	77	La I *Cr* I—
54	*Ba*			78	Sm—Re
56	*La* I—				
57	*Ru* Ru I—Sm II				

Intensity (**Ba** above 100; Cs 100 to 300; *Sn* below 100). (—) =0.5 A; no dash indicates greater than 0.5 A

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
5180	*Fe* Cb—	5239	*Eu*—	5300	*Cr* I
81	Zn I	40	*Cr* I—*V* I *Mo*	01	Pt **Co I**—**La II** (R)
83	**La II**—*Co* **Mg I**	42	Fe—*Mo*	02	**Fe I**—*La* II *Ba Sm*
84	Rh I—*Ni* I *Cr* I	43	*Cr* I—*Fe* I	03	*Fe* I—La II **Eu**
86	*Cb*	44	*Yb*—	04	*Cr* I—*Ru*
87	*Ce*—	47	*Fe* I—*Cr* I **Co I**	07	Tm Fe I—
88	*La* II—*Ti* II *Ca* I	48	*Eu*	08	*Ba*
89	*Cb*—	49	*Eu*—*Nd* Co I	09	Ru I—
91	**Fe I**—	50	*Fe* I—Fe I	10	*Co* I—
92	*Cr* I Co I **Fe I**—	51	Sm *Fe*	11	Hf II
	Ti I V I	53	La I *Fe* I—	12	Sm II—**Co I** *Cr* I
93	Cb—	54	Co I *Fe* I	15	*Fe* I—
94	Fe I	55	*Cr* I *Mn*—*Nd Er*	16	**Co I**
95	Ru I Fe I—	56	*Sr*—**Co I**	18	Cb *C* I
96	*Fe Cr* I—*Mn*	59	*Mo*—Pr	19	*Nd*
98	*Fe* I *Fe*	61	*Au* I	20	*Fe*—Sm
99	**Eu**	62	*Ca* I—	21	*Fe*—*Sm*
		63	**Fe I**—*Fe*	22	*Sm*—
5200	*Cr* I *Y* I—Sm **Eu**	64	Cr I (R)—*Hf* II	23	*K* I—
02	**Fe I**—*Sm* II	65	*Ca* I *Cr* I *Co* I *Co* I	24	**Fe I**—
04	*La* II—**Cr I** (R) Fe I		*Ti* I	25	**Co I**—*Co* I
05	*Y* II	66	*Fe* I Co I **Eu Co I**—	26	*Fe*—
06	**Cr I** (R)—		**Fe I**	27	Re—
08	**Cr I** (R)—**Fe I**	67	*Ba* I	28	**Fe I**—Fe I
09	**Ag I** (R)—	68	**Co I**	29	*Fe*
10	Co Ti I—*Co* I	69	*Rh* I—**Fe I**	31	**Co I**—*Re*
11	Co I **La I** (R) *Ce*	70	*Ca* I **Fe I**—Re	32	Co I *Fe* I
12	**Co I** *Ta*	71	La I Sm—Cb **Eu** *Ca*	33	Co I
13	Eu—	72	*Cr* I **Eu**—*Sm* II	34	*Ru Co* I *Cb*
15	**Eu** Fe I—	73	*Fe* I *Fe* I—	35	Yb—Ru
16	**Fe I**—	74	*Ce*—	36	*Co* I—
17	Eu Fe I—*Fe*	75	**Re**	39	Co I Fe I
18	**Cu I**—	76	**Co I** Cb—	40	*La* II
19	*Pr* Cb—*Ti* I	77	Yb—*Ba*	41	Fe I Ta Mn *Sm* **Co I**—
20	Cu I *Pr*—	78	Re—	42	*Ta*—**Co I** *K* I
21	*Cr*	79	*Ta*	43	**Co I** *Fe* I—
22	*Sr Co* I—	80	*Fe*—**Co I** *Mo*	44	**Cb**—
23	**Eu**—*Ti* I	81	**Fe I**	45	**Cr I** (R)
24	*Ti* I—*W Ti* I	82	**Eu** Sm	47	*Co* I—
25	*Sr*—*Fe* I	83	*Ti* I Co I—**Fe I**	48	Cr I (R)—
26	Fe I	84	Ru I—	49	*Co* I *Ta*—*Mn*
27	**Fe I**—*Pt*	87	*Cr* I Eu—Fe	50	*Eu* **Tl I** (R)—Cb
28	*Fe*—*Sm*	88	*Fe*	51	*Ti* I *Yb*—Eu
29	*Sr*—Fe I	89	Eu—	52	**Co I** *Pr*—*Eu* Yb
30	**Co I** (R) *Au* I—*Ta*	90	*La* II *Fe* I	53	*Fe* I *V* I *Ni* I **Co I**—
32	*Cb* **Fe I**	91	Eu—		*Ce*
34	*Sm Nd* La I (R)—	92	*Pr Rh* I—*Cu* I *Pr*	54	**Rh I**—*Ta*(R)
	Pd I	93	*Nd*—*Eu Fe*	55	Eu—
35	Co *Ni* I *Fe* I—	94	*Ba*—**Eu**	57	**Eu**
36	*Fe*—	95	Pd I *Ti* I	58	*Co* I
37	Rh I—	97	*Ti* I—	59	**Co I**—*K* I
38	*Mo*—*Sr Ti* I *Cr* I	98	*Hf* II—*Fe*	60	Mo Eu

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements
5361	Eu Ru
62	*Rb* I *Fe* **Co I**
64	*Mo Sm*—Fe
65	*Fe*—
67	Fe—
68	*Sm*—*Co Pt*
69	**Co I** Fe
71	*Ni* I **Fe I**—
73	*Fe* I
76	*Os Fe* I Eu
77	**Re**—*Mn*
78	*Fe*
79	Rh I—*Fe*
80	*La* II
81	Co I *Pr* Rh I—Co I
83	**Fe**—
86	*Cr*
87	*Sm*
89	Ta *Fe* I—
90	Rh I *Co* I—*Pt*
91	*Fe* I—
92	Eu
93	V I Fe I—
94	*Mn*
95	*Pd* I—*Er Ta*
97	*Ti* I **Fe I**—
98	*Fe* I—
99	*Mn*—
5400	Fe I *Cr*
01	Ru—V I Co I
02	*Ta* Lu **Eu**
03	*Fe*
04	**Fe I**—*Rh Ba Ta*
05	*Sm*—**Fe I**
07	*Mn*—Co I
08	*Co* I—
09	*Fe* I *Ce*—*Ti* I Cr I (R)
10	Fe I
11	*Ni* I—*Eu*
13	*Mn*
14	*Er*
15	**Fe I** *V* I—
16	Sm *Os*—*Os*
19	*Ta*(R)—
20	*Mn*—
21	Eu—*Lu*
24	Rh **Fe**—Ba I (R) *Ni* I
25	*Ba* I
26	Eu
27	*Ru*
5429	**Fe I**
31	Rb I *Ta*
32	*Mn*
34	*V* I—**Fe I**
35	*Ta*—*Ni* I
36	*Fe* I *Co* I
43	*Os*—Eu
44	**Co I**
45	Fe I—
46	**Fe I**
49	*Fe*
51	**Eu**
52	*Co* I—**Eu**
53	Sm—
54	Co I Ru
55	La I *Fe* I—**Fe I**
57	*Mn*—
61	*Ta*—
62	*Ni* I—*Fe* I
63	Fe I—
64	*Fe*—
65	**Ag** I (R)—
66	*Fe* I Y I—*Sm*
69	Co I—
70	*Co* I—*Mn*
71	**Ag I**
72	**Eu**—
73	*Mo*—*Ba* Fe I
74	Fe
75	*Pt*
76	*Fe*—*Fe* I Lu **Ni** I *Co* I
77	*Ti* I
78	*Pt*—
80	*Cr* Sr *Fe* I
81	*Fe* I *Mn Fe* I—*Yb* *Sc* I
83	*Fe* I **Co I**—Co I
84	*Ru* I—*Sc* I
87	*Fe* I—*Fe* I
88	**Eu**
89	Co I
90	*Ta Ti*—
92	*W*—*U*
93	*Sm*
94	*Ta*
95	Eu—
97	Fe I
98	*Sm*—
99	*Ta*—
5501	La Fe I—
03	La I *Ti* I
5504	*Sr*—
05	*Mn Fe* I
06	*La* I Mo(R)—Fe I
07	*V* I
09	*Pr*—
10	*Ni* I La I—**Eu** Ru
12	*Ce Sm*—Ti I
14	*Sc* I *Ti* I—*Tb Ti* I *W*
16	Sm *Tb*—*Mn*
18	Ta
19	Ba I (R)—
20	*Sc* I—
21	*Sr*
22	*Fe* I—Ce
23	**Co I**—Os *Co* I
25	*Fe* I
26	*Eu* Sc II
27	Y I
28	*Mg* I—
30	**Co I**
32	*Na* I—Re
33	Mo—
34	*Fe* I
35	*Rh Fe*—**Ba** I (R) *La*
37	*Sm* II—*Mn*
38	*Fe*
39	Yb *Fe*—
41	*La* I—
42	*Eu* Pd I
43	*Fe*—*Fe* I
44	*Rh* I
45	*Co* I *Ag* I
46	*Fe* I—
47	*Pd* I **Eu**—
48	*Ta*—*Sm*
50	Sm—
52	**Bi**—
53	*Fe* I
54	Fe I
56	**Yb**—
57	*Al* I—*Al* I
59	*Ru* I
60	*Fe* I—
62	*Fe* I
63	Re—Fe I
65	*Ti* I—*Fe* I
66	Ho
67	*Fe* I—
69	**Fe I**
70	**Eu** Mo—
72	**Fe I**

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5

TABLE V (*Continued*)

Principal Lines by Wavelength

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
5573	*Fe* I *Sm*—	5651	*Yb*	5724	**Rb I**—*Rb* I
74	*Sm*	53	Rb I	26	*Au* I
76	Fe I *Cb*—	55	*Fe* I—*Au* I	27	V I—*V* I
77	**Eu**—	57	V I—*La* I	28	*In* I—
78	*Ni* I Rb I	58	*Fe* I Fe I	30	**Eu**
79	Eu	59	*Co* I—*Sm*	31	V I—*Fe* I
80	**Eu**—	62	Ti I—*Fe* I	32	Sm
81	Y I *Ca* I	64	*Zr* I *Cb*(R) *Ta*	35	*W*—
84	*Ta Os*—*Fe*	65	Cb	36	Lu
86	**Eu—Fe I Eu**	67	*Fe* I Re	37	V I—
87	*Fe Ni* I	68	*V* I—	38	**Eu**
88	*Ca* I	69	*Ce*	39	*Ti* I
89	*Ni* I—	70	Pd I Na I—V I	40	*Re*—La I *Sm*
90	*Ca* I—**Co I**	71	Cb—**Sc I**	41	*Sm*—
92	Ni I (R) *V* I—	73	Eu	42	*Bi*
93	*Ba*—*Ni* I	74	Ho	43	*V* I—
94	Nd *Ca* I *Co*—*Fe*	75	*Ti* I—Na I Tm	44	*La* I—
98	*Fe* I *Ca* I *Co*—*Ta*	79	*Ti* I	46	*Ta*
99	**Rh I**—	80	*Ba* I—*Zr* I	47	*Tb*
		82	*Ni* I—*Na* I	48	*Ni* I—
5600	Sm II	83	*V*—	50	*V* I
01	*Ca* I *Ce*—	84	Eu—	51	Mo—
02	*Fe* I *Ca* I *Fe* I	86	Rh I—*Fe Sm* Sc I	52	*Fe* I—Re
03	Sm II—	88	**Na I** Ta—Nd *Na*	53	*Fe* I—
04	*V* I	89	*Mo Ti* I—	54	*Si* I—Ni I
14	*Ni* I	90	*Si* I—	59	*Sm* II
15	**Fe I**	91	Ho—	60	*Ni* I
18	*Fe* I *Ba* Eu	92	*Pb*—	61	*La* I
19	*Ba Pd* I—	94	*Cr* I *Ni* I	62	*Ti* I—
20	Nd *Ta*	95	*Pd* I—	63	*Fe* I—
21	*Sm*—	96	*La* I—	64	*Tm*—
24	Fe I V	98	*Cr* I—**V I**	65	**Eu**—
25	*Ni* I—	99	Ru I *Ta*—	66	*Ti* I—*Ta*
26	*Sm* V I—			67	Ta
27	V I	5700	**Sc I** (R) **Cu I**—	69	*La* I—**Hg I**
28	*Cr* I	01	*Fe* I	72	*V* I—
30	*Y* I *Fe*—	02	*Cr*—*Ti* I	73	Sm
31	*La* I *Tm*—*Sn*	03	V I	74	*Ti* I—
32	Mo—Eu	05	*Fe* I	75	*Fe* I *Lu*—
33	*Fe*	06	*Ta*—*Ho* V I	76	*V* I *Ta* **Re**
36	*Co* I Ru I—	07	Pr	77	**Ba** I (R)
37	*Sm*—*Co* I	08	*Nd*—	78	*Sm*—
38	*Fe* I—	09	Fe I—Ni I *In* I	79	*Sm Pr*—
40	Ho	11	Sc I *Ti* I *Ni* I	80	*Ta Si* I—*Ta O*
41	*Fe* I—*Ni* I	13	*Ba*	81	Sm
42	*Cb*—	15	*Ni* I *Ti* I—	82	**Cu I**—*K* I
44	Ti I—	16	*V* I—	83	*Cr*—Eu *Cr*
45	**Eu** *Ta*	17	*Fe* I	84	*V* I—
46	V I—	19	*Sm*—	85	*Cr*—Ti I
47	**Co I**—	20	**Yb**—	86	*V* I—Sm II
48	**Rb I La I** *W*—*Ti* I	21	*Au* I—*Os*	87	*Cb Cr*
50	*Mo*—	22	*Mo*	89	La I—*Fe*

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (--) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
5791	*Cr* I *Fe* I La I—Mo	5883	*Fe* I	5969	*Fe* I
93	*C* I	88	*Cr* Mo—	71	*U* Ba I
97	*La* II *Zr* I *Si* I	89	**Na I (R)** Mo	72	**Eu** Ba
		91	Eu—	73	Ho
5800	Eu Ba I—*Sm Os*	92	*Ho*	75	*Fe*—
01	*K* I	93	*Mo*—	76	*U*—
02	*Sm*	95	*Tm Pb* **Na I (R)**	78	Ti I V I
04	Nd Ti I—	97	Sm—	80	*V* I
05	*Ni* I—*Ba La* II	99	Ti I—	82	Ho
06	*Fe* I Rh I			83	Rh I *Fe* I
07	*V* I—	5900	Cb	84	*Fe* I
11	Ta—	01	*Ta*	87	*Fe* I—
12	*K* I	02	*Fe*	91	*Yb* **Co I (R)**
14	*Sm*	05	*Fe*	92	**Eu**
15	*Ru* I—*Re*	06	*Fe*—	94	*Sm* II
16	*Fe*—	07	*Ba*	95	*Os*
17	*V* I—V I	08	*Fe Fe*—	97	Ba I *Lu* Ta *Sm* II—*Cb*
18	**Eu II**	10	*Fe*		
23	*Pr*	12	*Fe*	99	*Ti* I *Fe*
25	*Fe*	14	*Fe* I—		
26	Ba I—	15	U—Co I Eu	6000	*Co* I
30	*Fe* V I	16	*Fe* I—	01	*Sm Pb*
31	*Sm* II **Eu**—*Rh* I	18	*Fe*—*Ti* I *Ta*	03	*Fe* I—
32	*K* I—	19	*Sm*—	04	**Eu—Lu**
34	*Yb* Re—*Fe*	21	Ho	05	*Eu*
36	Sm II—	22	Ti I—	06	*Co* I—
37	*Yb* **Au I**—	24	Ni I	07	*Ni* I *La* I—*Co* I *Fe* I
38	Cb	26	*Mo*—*Eu*	08	*Fe* I
40	*Pt*—	27	*Fe*	10	*Cs* I—
42	*Hf* II *Fe*—	28	Mo	11	*Sm* II—
45	*Fe*	30	*Fe* I—La I La I	12	**Eu—Eu**
46	V I—	32	*Ti*—*Sm* II	13	Mn—Fe *Co* I
48	*Mo*	33	Ho	15	Eu
49	*Ta Mo Ta*	34	*Fe* I	16	*Mn Co* Fe I
53	**Ba**	35	Co I—	17	*Sm* II—
56	*Fe*—	37	*Ti* I	18	**Eu**—
57	*Ca* I *Co*—*Ni* I *Os*	38	*Sm* II—*Ta*	19	Ba I—
58	Mo—	40	*Fe* I	20	*Fe* I—**Ta** (R)
59	*Fe*—*Fe* I	41	Ti I	21	*Co Mn* **Fe I**
60	Ho—	43	Re—	22	*Au* II
62	*Fe* I—*Au* I	44	*Ta*—	23	Eu—
66	**Ti I** *Cb*—*Ta*	46	*Co* I—	24	*Fe* I *Ce*—
67	*Sm*	48	Ho—*Si* I	29	**Eu**—
69	*Mo*—*Fe*	52	*Fe* I	30	**Mo**
72	**Eu II**	53	Ti I—	31	*Cd* I—
73	*Fe* I—	55	Ho	34	*Cs* I—
75	*Fe*—	56	*Fe* I *Au* I	38	*La* I
77	Ta—	62	*Au*	39	V I
78	*Fe*—	63	Eu—	44	Eu *Sm*
79	*Fe Zr* I *Fe* I	65	Sm II Ti I	45	Ta—
80	*Ti* I—	66	**Eu**—	47	Ta—
82	*Ta*—Ho	67	**Eu**—	49	*Co* I—**Eu II**

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
6053	Ta	6151	*Fe* I	6246	*Fe* I—*Sm* II
55	Lu **Pr**—	52	*Ta Yb*	48	*Hf* II
56	*Fe* I—	54	**Na I**—Ta *Sn*	49	Co I Ta **La I**
57	**Eu**—	55	*Si* I *Si* I—	50	*Eu*—
58	*V* I—	57	*Fe*	51	*V* I
63	Ba I—	58	*Ta*	52	*Fe* I
64	*Ti* I	59	**Rb I** *Lu*	54	*Fe* I—*Si* I
65	*Fe* I—	60	*Au* I—**Na I**	56	**Ni I** *Fe* I—*Sm* II **Ta**
70	*Co* I **Rb I**	61	*Pr Ca* I—	57	*Co* I
75	**Eu**	62	*Co Ca* I *Au*—	58	Ti I—**Ti I**
77	**V I** Eu—	63	Ni I—*Ca* I	61	**Ti I**—
78	*Fe* I—	65	La I *Pr*	62	**Eu** La II—
81	V I—	66	*Ca* I—	65	*Fe* I—
82	Co I—	69	*Ca* I—*Ca* I	66	*La* I *Ta*—Eu
83	*Ba*—**Eu**	70	**As II** *Fe* I	67	*Sm* II—
84	*Sm*—	71	*Sn*—	68	*Cu* I—Ta
85	Ti I—	73	**Eu I** *Fe* I—	73	*Co* I—
86	Ni I—*Co* I	75	**Ni I**—	74	*V* I Yb
90	*V* I—*Ta*	76	**Ni I**	75	*Co* I—
91	Ti I—	78	Eu	76	*Co* I
93	Co I—	80	*Fe* I—	78	**Au I**—
98	*Ti* I	81	*Sm* II—	81	*Ta*—
99	**Cd I Eu**—	82	*Sm* II	82	**Co I**
		86	*Ni* I	85	*V* I—
6101	**As II** Ta—**As II**	88	**Eu**—Co I	88	**Eu**—
02	*Fe* I—Rh *Ca* I	89	*Ta*	89	*Sm* II
03	*Fe* I—**Li I** (R)	91	**Ni I—Fe I**	90	*Fe* I
07	*Co* I	92	*Sm*	91	Eu—**Sm II**
08	Ni I Eu *La* I—	95	**Eu**—	92	*V* I
10	Ba I	99	V I—	96	*La* II—
11	*Ni* I—Cd I *La* I			97	*Fe* I
16	Ni I *Cd* I—*Co* I	6200	*Fe* I—	98	**Rb I**—
18	**Eu**	06	**Rb I**—	99	**Rb I**—*Zr* I **Eu**
19	*Cu*	11	*Co* I—		
21	*Zr* I	12	Cs I	6300	*Sm* II—
22	Ca I *Co*—Co I	13	*Fe* I—*V* I	01	*Sm* II—*Fe* I
23	*Sm* II	15	Ti I—	02	*Fe* I
24	Eu	16	*V* I—	03	**Eu II—Ti I**
26	Ti I—	19	*Fe* I—	05	Gd—*Sc* I
27	Zr I—*Cu* I *Fe* I	20	Ti I—	07	*Sm* II—Re I
29	*Co* I—	21	*Ti* I—**Lu**	09	Ta
34	*La* I (R)—**Zr I**	23	*Ni* I	10	*Nd*—
36	Fe I	24	*V* I	11	*Co*—
40	*Ba*—	27	*Fe*—	12	*Ti* I—
41	**Ba** *Fe* I	30	*Fe* I *V* I Co I	13	Zr I *Co* I—
42	*La* I	32	*Co* I—*Fe* I	14	*Co* I **Ni I**
43	Zr I—	33	*Ba* Eu—	15	*Fe* I—
44	*Ta*	35	*Pb*—	18	*Fe* I *Ti* I—
45	*Re*	37	*Sm* II	19	*Rh* I
46	**Ti I**—*Re* I	40	**Li I**—	20	*La* II *Co* I—
47	*Cu* I—*Fe* II	43	*Re* I—	21	*Sm* Re I—
49	*Sm* II—	44	*Si* I *Si* I	22	*Fe* I

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
6325	Ta Cd I—*Sm*	6424	Mo—	6527	*Ba*—
26	*Pt*	26	Sm II	29	*Cr*—*Sm*
27	Sm II—*Ni* I	28	Eu *Sm*—	37	*Cr* I
29	*Cd* I	29	*Co* I	38	*Gd*—*Y* I
30	Cr I—	30	*Co* I *Cb*—Ta Fe I	42	Sm II
32	*Ta*	31	*Sm* II—*Sm* II	43	La I—
35	*Fe* I—Eu	35	Y I—	44	*Cb*
36	*Ti* I—*Fe* I	37	**Eu I Cd** I—	45	*Mg* II—
39	*Ni* I—	39	Ca I *Co*—	46	Fe I *Ti* I—*Sr* I
41	*Ta*—*Ba*	40	*Mn*	49	**Tl I** Sm II
44	*Fe* I—	44	*Co* I *Ru*	50	Sr I—
45	*Lu*—*Sr* I	46	*Ba* (R)	51	*Co* I—
47	Co	49	U—*Ca* I	52	Ti II
50	**Eu**—Re I (R)	50	**Co I** Ta—Ba	54	Ti I—
51	*Co* I—	51	*Co* I—	56	Ti I—
53	*Sm*—	54	La I Co I	62	*Sm*
55	*Fe* I—Eu	55	La I	63	Co I—
56	Ta—	56	*Au* II	65	*Ti* I—
57	*Sm*—	57	**Eu**—	67	**Eu**
58	*Fe* I	60	**Tm**—	69	*Fe* I **Sm II**—
60	Ta	62	Ca I *Gd Co Fe* I	70	Sm II
62	**Zn I**—Cr I	63	*Co* I **Lu**—	72	*Ca* I *Cr* I
66	*Ti* I—	69	*Fe* I—	74	Sm II—Ta
68	*Sm* II—	70	*Sm* II—	77	*Re* I—
69	**Eu**—	71	*Mo*—*Ca*	78	La I
72	*U*—	72	Sm II—	80	*Cr* I
73	*Ta*—	75	*Fe* I	85	Sm II—
78	*Ni* I—*Mn*	77	*Co* I	86	*Cs Ni* I *Mn*—**Cs I**
80	*Fe* Gd	81	*Fe* I	88	Sm
82	*Mn Gd*—Eu	82	*Ni* I Ba	89	**Sm II**
83	Eu	84	Sm II	92	*Re* I Fe I
84	*Mn*	85	**Ta**—*La* I	93	**Eu** *Fe* I
85	Nd—	87	*Sm* II	94	*Cr*
86	*Sr* I	89	**Yb**—*Zr* I	95	**Ba I**—Co I
88	*Sr* I—	90	*Co* I—*Sm* II	97	*Fe* I
89	Ta—Sm II	91	Mn	99	Ti I—*Cu* I
90	*La* II—Sm II	93	*Co Ca* I		
93	Fe I	94	**Fe I**	6601	Sm II
94	La I—	96	*Fe*—**Ba** (R)	03	*Eu*
95	Co I U—	98	Sm II *Ba*	04	Sm II **Tm**
		99	*Ca* I	05	Re I—*Mn*
6400	Fe I Yb—**Eu**			08	*La* I—*Cr*
06	Eu—	6501	*Cr*—**Eu**	09	*Fe* I—
08	*Fe* I *Sr*—	03	*Sr*	11	Lu **Ta**
10	**Eu**—La I	05	Ta	14	*Sm* II
11	**Eu**—Fe I	11	*Re* I—	16	La II
13	*Mn*	14	Ta—	17	*Co* I Sr I—*Co* I *Sm* II
14	*Rh* I	16	Ta—	19	**Mo**—
17	Sm II Co I (R) Yb	18	*Mn*	21	Ta—*Cu* I
19	*Fe* I	19	*Mn*—**Eu**	23	*Co*
21	*Fe* I *Cr*—*Co* I	23	*Lu Pt*—	28	*Cs* I *Sm* II
22	*Gd*—	26	*Sm* La II	30	*Cr* I—*Sm* II

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 10.0). (—) = 0.5 A; no dash indicates greater than 0.5 A

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
6632	Sm II Co I—	6730	Gd	6823	*La* I
33	*Fe* I	31	**Sm** II	24	Ru—
34	Gd—	33	*Fe* I—*Mo*	28	Cb Gd—*Fe* I *Mo*
35	*Co* I—	34	**Sm** II—**Sm**	29	Sm II Re I
37	*Sm* II—	35	Sm—	30	*Ir* I—
43	*Yb* Sr I **Ni** I	39	*Cb*	33	*Mn*
44	Hf II	40	*Ta*	41	*Eu* *Fe* I—
45	**Eu** Gd—	41	*Cu* I—	42	*Ni* I—*Fe* I
49	*Sm* II—	43	Ti—	43	*Fe* I
50	*Mo*—La I	44	Eu	44	Tm—Sm II
51	*Sm* II	46	*Mo*—	45	Tm
52	*Re*—*Au* I	50	*Fe* I—	46	Sm II **Gd** *Co* I
54	*Ba* I—	51	*Re*—	47	*In* I
56	Sm II—	52	*Re* Rh I—**Gd**	54	*Sm* II
57	*Tm*	53	La I—Gd	55	*Fe* I
60	**Cb**	54	*Hf* II *Sm* II	56	**Sm** II—
61	Cr I *La* I—	56	*Co* I *Sm* II	57	Gd *Fe*—
63	Ru *Fe* I—	58	*Co* I—	58	*Fe* I—
67	*Sm* II—**Yb**	60	Pt—	60	**Sm** I
69	*Cr* I—	62	*Zr* I *Cr*—	61	**Sm** II *Ti* I
71	*Sm* I—	66	*Sm* II	62	*Fe* I—Sm II
72	*Cu* I—	67	*Co* I **Ni** I	64	**Eu**
73	Ta	68	*Yb*	65	Ba I
75	**Ba** I—**Ta**	69	*Zr* I—	66	Ta—
77	Cb—Fe I	71	Co—Ta *Ba* I	67	Ba I
78	Co I	72	Ni I—	70	Cs I—
79	*Sm* *Sm* II—	74	La II Ta—	72	Co I Sm II—
81	Gd—*Sm* II	78	*Cd* I—Sm II	75	Ta *Cb*—
84	*Co*—*Co* I	79	**Tm**	78	**Sr** I—
85	*Eu*—	81	*Sm* II—	81	*Cr* I
87	*Y* I *Sm* II	82	Eu	82	*Cr* I—
90	**Ru**—	84	*Co* I	83	*Cr* I—
91	*Mn*	86	Gd—	85	*Fe* I
92	*La* I	88	*Ta*	87	*Mn*
93	Sm II **Ba** I **Eu**	89	*Cr* *Co* I *Hf*	92	Sr I
96	*Al* II—	90	**Sm** II—		
98	*Al*	91	Sr I—	6900	*In* I—*Ta* *Gd*
		93	*Y* I	02	Ta—*Cb*
6701	Cb—	94	Sm II—	03	Eu
03	*Fe* I	99	**Yb**	05	*Co* I
05	*Fe* I—			08	*Co*—
07	*Sm* II—**Li** I (R)	6802	**Eu**	09	*Sm* II
09	La I—	04	*Fe* I—	10	*Co* I
10	*Pt*—	06	*Fe* I	11	**K** Ru—
12	*Sm* II	08	*Co* I	14	**Ni** I
13	Tl I	10	*Fe* I—	16	Gd *Fe* I
15	*Fe* I—	13	Ta Re—*Ni* I	17	*Lu*—
17	*Fe* I	14	Co I (R)	18	*Cb*—
21	*Tm*—	16	Eu—	20	Cu I—
23	Cs—Cb	18	Hf	23	**Ru**—
26	*Fe*	19	*Co*	24	*Cr* I—
27	*Gd*	20	*Fe*—*Gd*	25	*Cr* I La I-

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
6927	Ta—	7034	*Ni* I—*Si* I	7134	Co I—
28	*Zn* I—**Ta**	37	*Gd*—	36	*Sm*—
30	*Sm* II—	38	*Fe* I—Ti I	42	*Fe* I
31	*Mn*—	39	**Sm II** *Cu* I	45	*Fe* I—
33	*Fe* I	40	**Eu**—	47	*Gd*—
34	*La* I	42	**Sm II**—	48	**Ca** I—Ta
37	Co I	45	La I	49	Sm II
38	**K I**	46	**Cb**	51	*Mn* Fe I—
41	*Sm* II	51	**Sm II**	53	*Ba* I
42	Mn	52	**Co I**	54	Co I
45	*Fe* I—	54	Co I—	55	*Fe* I
50	Sm II	55	*Co* I	58	La I—
51	Ta *Fe* I—	59	**Ba I**	59	Co I Cb—
53	*Zr* I *Ta*	62	*Ni* I	61	La I—
55	*Ni* I **Sm II**—	66	La II—	64	Fe I—*Eu*
65	**Rh**	68	La I *Fe* I—	65	Si I
66	Ta—	69	*Mn*	67	*Ni* I Sr I—
71	Re I	70	**Sr I**—	68	*Gd*—
73	**Cs**—	74	*Eu Sm*	69	Zr I—
76	*Si*	77	**Eu**—	72	*Gd*—Ta
78	Cr I—*Fe* I	81	*Ta*—	75	Eu *Fe* I
79	*Cr* I	82	**Sm II**—	76	*Fe* I
80	**Hf II**	83	*Fe* I—	81	*Fe* I
82	Ru—	84	**Co I**	82	Ni I—
83	*Cs* I—	88	*Sm* I—	84	*Mn*—
85	Gd	90	Ba I *Fe* I	87	**Fe** I—
88	*Fe* I	91	*Sm* I—	89	*Fe* I—*Gd*
89	*Mn*	94	*Co* I	93	Co I
90	Cb—*Zr* I	95	*Fe* I—Sm I	94	**Eu** I *Gd Fe*
91	Gd	96	*Sm* I—Zr I	95	Ba I—
95	**Ta**	98	*Cb*	97	Ni I—
96	Gd				
97	Co I—	7101	*Rh* I	7202	*Ca* I—
99	*Fe* I	02	*Co Zr* I	03	Ca I—
		03	*Zr* I	07	**Fe** I—*Cr*
7001	*Ni* I	04	*Rh* I—Sm I *La* II	08	*Ba* I—
03	*Si* I	06	*Sm* I **Eu**—	09	Ti I—
04	Co I	07	*Fe* I—	12	*Fe* I—
05	*Ta*—*Si* I	09	*Mo*	13	*Ba* I *Sm* I
06	*Gd*—Re I **Ta**	10	Ni I	16	*Ti* I—
08	*Fe* I—	13	Co I *Pt* I	17	**Eu** I
16	Fe I—**Co I**	15	*Sm*	18	*Sm* II—
17	*Si* I	18	*C* I	19	*Fe*
20	**Sm II**—	19	*Sm*	21	*Fe* I—
23	*Fe* I—La I	20	**Ba** I—	23	*Fe* I
24	*Fe* Re I—*Fe* I *N*	22	**Ni** I *Co*—*Gd*	24	Eu
25	*Ta*—	24	*Co* I—	28	**Cs** *Fe* I Ba I
26	Sm I	25	*Ta* Lu	29	*Pb*—
27	Co I Ru I	26	*Ba*	32	*Sr* I—
30	Ni I—	30	Fe I	33	*Gd*—
31	*Lu*—	31	*Sm* I Hf	37	Hf—
32	*Co* I	32	*Cd*—*Fe*	38	Ru

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
7239	*Fe* I	7336	**Eu**—	7437	*Co* I—
40	*Hf* Sm II	38	*Sm*—*V* I	40	Ti I *Fe* I
42	*Mo*	44	Ti I	41	Gd
44	*Fe* I Ti I	45	La I	42	Rh I—
45	*Mo*	46	**Cd** I Ta—	43	*Fe* I—
46	**Re** I	47	Sm I—	44	Sm
47	*Mn*	51	*Fe* I—*Fe* I	45	*Sm* I—Fe I
50	*Co* I *Ta*—*Si* I	52	*Re*—Ta	57	Co I—
51	Ti I	53	*Cb* *Co* I—	59	**Ba** I
52	*Gd*	54	Co I	62	*Cr* I—
54	*Fe*	55	*Cr* I	64	Gd—
58	Eu	56	Ta	68	Ru
61	*Fe* I **Ni** I	57	Ti	70	Sm
62	*Gd* Eu	59	*Ba* I—	75	*Ru*—Rh I
68	Rh I—	62	*Eu*—	76	*Ba* I *Fe* I—
70	Rh I	63	*Fe* I	81	Tm—
71	*Rh* I	64	*Sm* Ti—	85	Mo Ru **Ta**
73	Re I	69	Ta—Eu	88	Ba I—
75	*Si* I—	70	**Eu** I *Gd*—	89	Ti I
79	Sm I—**Rb** I	71	*Sm* I	90	Tm—
80	**Ba** I—	73	*Si* I—	91	*Fe* I
81	*Eu*	75	*Ba* I	95	Fe I Rh I—
82	*La* II *Fe*—	76	*Fe*—*Sm* II	99	Ru
83	**Mn**	81	*Ni* I		
84	*Fe*	82	Cb *Fe* I	7502	*Sm* II—
85	Co I—	83	**Cd**	07	*Fe* I—
88	*Fe* I	85	Ni I **Cd** I—	10	*Au* I
89	Si I—	86	Ni I *Fe*—	11	*Fe* I—
90	*Sm*—*Ni* I	88	Co I	22	*Ni* I *Ba* I
91	*Gd* Ni I—	89	Fe I—	25	*Ni* I—
92	**Re**	91	*Mo*—	27	*Yb*
93	Fe I—	92	**Ba** I—	28	*Ba* I—Eu
94	*Fe*	93	*Cd*—**Ni** I Ru	31	*Fe* I—
99	*Ti* I	99	*Cd* I—	33	*Co* I—
				41	Sm II—
7300	*Fe*—	7400	*Cr* I—	43	*Ba* I—
01	**Eu** II Gd—Ta	01	*Fe* I	44	*Sm*
02	**Mn**	05	*Sm*—**Si** I	53	Co I
06	*Fe* I	07	Ta	55	*Ni* I
07	*Ba* I—*Fe*	08	**Rb** I—	58	Tm—
09	Sr I—	09	Si I **Ni** I—*Ba* I	59	Ru I
11	*Fe* I—	11	Fe I—	62	*Sm*
13	Gd—*Eu*	14	Ni I	64	*Co* I
15	*Co* I	15	*Si* I—	70	*Cu* I—Sm II
18	*Ti* I—	16	Si I—	72	*Sm*—
20	*Fe* II	17	Co I—Ba I *Gd*	74	*Ni* I—Cb
24	*Gd*	18	*Fe*	78	*Sm* II—Re I
26	**Ca** I—*Ba* I **Mn** I	22	**Ni** I—**Si** I	83	*Fe* I *Ba* **Eu**
27	*Ni* I	24	*Si* I	85	*Sm* II
32	Sm I	26	*Gd* **Eu**	86	*Fe* I—*Co* I
33	*Fe* I	30	*Fe* I	90	*Co* I
34	La I—	36	Eu		

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A.

TABLE V (*Continued*)

PRINCIPAL LINES BY WAVELENGTH

Wave-length	Elements	Wave-length	Elements	Wave-length	Elements
7607	*Sm* I	7749	Sm II—	7882	Ta—
09	**Cs**—	51	*Fe* I—*Ba* I	85	*Cb*—
10	*Co* I *Ba* I—	54	Sn I	87	**Eu**
11	Re I	55	Sm II *Sm* I—	95	Sm I
17	*Ni* I—	57	**Rb** I		
18	**Rb** I	59	**Rb** I—	7905	**Ba** I
19	*Ni* I—	64	Mn I	08	*Co* I
20	Re I—Fe I	66	*Ba* I	10	*Sn*—
21	Sr I	71	Ru	11	Ba I—
36	*Ba* I	72	Rh I	12	*Fe* I **Re** I
37	*Sm* II	74	Ru—	13	*Sm*—
40	**Re** I	75	*Ba* I *Ru*—	14	Sm II
42	Ba I	80	**Ba** I—*Fe* I	17	*Ni* I—
45	Sm II—*Sm*	88	*Ni* I	18	Si—
48	Sm II—	91	Rh I Ru Ru I	19	*Sm* I—
53	*Fe* I	94	Sm I	24	**Sb**
55	*Sm* II	97	*Ni* I	25	Rb I—*Rb* I
61	*Fe* I—			26	*Co* I
64	*Fe* I—**K** I (R)	7800	**Rb** I (R)—	27	*Tm*
67	*Sm* II—*Mn*	01	Sm I	28	**Sm** II—
72	**Ba** I *Sm*—	08	*Sn* I—	30	Tm
73	Sr I—	09	*Co* I—	31	*Sm*—Sm I
78	*Sm* II	12	*Sm*	32	**Si** I—
80	Mn I Si I—	14	*Ta*—	33	Cu I—
85	*Sn* I—	20	Sm II—	37	Sm II *Fe* I—
87	*Ag* I	24	Rh	40	Sm—
95	Sm	29	*Mo*	41	*Fe* I—
98	**K** I (R)	30	*Rh* I—	43	**Si**
99	**Yb**—	31	*Sm*—	44	**Cs**—
		32	*Fe* I—	45	*Fe* I
7706	*Ba* I	35	**Sm** II—	47	**Rb** I (R)
10	*Fe* I—	36	*Al*	48	Sm II—
11	*Fe* II	37	**Sm** II—	49	*Ti* I—
12	*Sm* II *Mn* I—*Co* I	38	*Co* I—**Bi**	50	*Ta*—
14	*Ni* I—	39	*Ba* I	57	*Co* I
15	*Ni* I	40	*Co* I—	60	*As* I—*Co* I
20	*Mo*	42	*Ta*	61	*Ba* I—
21	*Ba* I	44	Sb—*Sm* II	66	*Co* I—
26	*Cb*	46	*Rh* I	68	*Sm*—
27	*Ni* I	47	Ru I	69	*Sb*
28	Sm II	55	*Co* I	70	*Si*—
31	Tm	56	*Tm*—	75	*Bi*
33	*Mn* I—	59	Sm I	78	Ti I
34	*Co* I *Mn* I—	63	Sm II *Ni* I	80	**Re** I
36	Sm—	69	Re I *Co* I	82	*Ba* I—
41	*Sc* I—	71	*Co* I—	87	*Co* I—
42	**Eu**	77	*Ba* I	90	Cs
46	**Eu**—	80	Sm II—	94	*Fe*—
48	*Fe* I—	81	Ru—		

Intensity (**Ba** above 300; Cs 100 to 300; *Sn* below 100). (—) = 0.5 A; no dash indicates greater than 0.5 A

TABLE VI

Principal Lines by Elements

(*A52*, *A48*, *A35*, *A28*, *A29*, *A83*, *A68*, *A86*)

I, II, and III indicate ionization states, R indicates reversal, p indicates persistent line. Symbols after the wavelength indicate lines used for qualitative and quantitative analysis and refer to the control lines listed with the same element. Interfering lines are those which may cause trouble if present in the sample. No wavelength values are given for these lines, but they can easily be determined by checking the lines of the interfering element for a wavelength value approximately the same as the line of the element to be identified.

Qualitative Analysis

*, †, ‡, §, ‖, ¶, ** = Gerlach and Riedl (*A29*).
C = Pierce (*C162*), Emery (*A36*), and Brode; see also Table IV, page 408.

Quantitative Analysis

L = Lundegårdh (spark) (*A68*).
F = Lundegårdh (flame) (*A68*).
S = Scheibe (*A81* and other publications).

Quantitative Analysis

G = Gerlach (*A28*, *A30* and other publications).
N = Smith (*A85* and other publications).
B = Brode (*C28*, *C52* and other publications).
M = Duffendack, Owens, Sawyer (*C68*, *C77* and other publications).
R = Ruehle and others.
D = Owens, Hess, and others.
A = *Spectrochimica Acta*.
X = Miscellaneous.

Subnumbers, S_2, B_3, etc., indicate pair combinations of unknown and control lines.

Arc and spark intensities are from 1 to 9000 as given in the Harrison-M.I.T. Tables ((*A59*).

The symbols (+) and (°) in front of the wavelength value (see iron table) indicate secondary and tertiary standards, respectively.

For more complete information on control and interfering lines one should consult Gerlach and Riedl, "Tabellen zur qualitativen Analyse, Die chemische Emissionsspektralanalyse," Vol. III (*A29*), and the literature publications of Duffendack, Scheibe, Gerlach, Smith, Lundegårdh, Brode, and others.

More complete information on the lines of elements, arranged according to element, including those elements and lines omitted from these tables can be found in Kayser (*A52*), International Critical Tables (*A48*), (*A35*), and other sources indicated in Chapter IV (page 74).

ALUMINUM

Al

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 094.8	—	50	I 2 378.4	40	20	I 3 082.2p*$S_1A_1X_1$C	800	800
I 2 168.8	8R	12	2 568.0A_3C	200R	80R	I 3 092.7p†X_1X_2C	1000	1000
I 2 174.0	8R	10	2 575.1C	200R	80R	3 092.8S_2	50R	18
2 204.6	10R	10	2 575.4C	30	30	II 3 586.9	...	500
I 2 210.0	12R	15	I 2 652.5	150R	60	I 3 944.0p‡LS_3B_1C	2000	1000
I 2 259.9	8	—	I 2 660.4X_1	150R	60	I 3 961.5p§LB_2C	3000	2000
I 2 263.5	60R	25	II 2 669.2	3	100	II 4 962.1C	15	3
I 2 269.1	60R	25	II 2 816.2A_2	10	100	I 5 557.0	15	...
I 2 269.2	15R	...	3 050.1	18	10	I 5 557.9	15	...
I 2 367.1	150R	50R	3 054.7	20	10	II 6 231.8	—	30
I 2 372.1	18	10	3 057.2	15	18	II 6 243.4	—	100
I 2 373.1	100R	30	3 064.3	20	20	II 6 696.4	10	...
I 2 373.4	200R	100R	3 066.2	25	25	6 698.8	10	...
						7 836.9	15	...

Control lines:
*Fe 3075.7
†Fe 3222.1
‡Ti 3981.8
§Co 3917.1
Cr 3919.2

Interfering lines:
*Au Cd Co Mo V W
†Au Fe Mg Mo V
‡Ba Co Fe Mo Ni V W
§Ca Co Fe Mo Ni Sr Sb W

Control lines:
A_1Zn 3076
A_2Zn 2801
A_3Mg 2916
B_1Ca 3933.7
B_2Ca 3968.5

Control lines:
S_1Cu 3128.7
S_2Cu 3094.0
S_3Cu 4022.7
X_1Mo 3158
X_2Mo 3208

TABLE VI (*Continued*)

Principal Lines by Elements

ANTIMONY

Sb

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 039.6	15	15	2 373.6	75	25	II 3 022.2	..	60
2 049.5	15	15	2 383.6S_3	75	20	3 029.8S_8N_8	100	200
2 054.0	30	5	2 395.2	50	15	II 3 040.7S_9	..	400
2 063.4	30	12	2 422.1	50	20	I 3 232.5p$S_{10}N_8$	150	250
I 2 068.4	300R	3	2 426.4	75	25	I 3 267.5pB	150	150
2 098.5	30	30	2 445.5	75	30	3 383.1	40	50
2 127.5	25	15	2 474.6	25	10	3 473.9	3	300
2 139.8	30	30	2 478.3	75	100	II 3 498.5	..	300
2 141.8	30	30	2 480.4	25	9	3 504.5	20	18
2 145.0	20	20	2 510.5	50	20	3 559.2	2	50
2 159.0	20	10	2 514.6	30	9	3 597.5	2	200
2 175.9p	300	40	2 520.2	20	5	3 637.8	2	60
2 179.3	35	40	I 2 528.5†S_4N_2C	300R	200	II 3 722.8	40	50
2 201.4	40	25	2 554.3	30	10	4 033.5	70	60
2 208.5	25	20	2 574.1	30	40	II 4 195.2	..	50
I 2 210.9	30	30	I 2 598.1p‡S_5N_3C	200	100	4 591.9	..	20
2 220.8	30	20	2 612.3	50	60	II 5 568.1	6	200
2 222.1	25	15	2 652.6	50	75	5 632.0	15	..
2 224.9	30	25	2 670.6S_6N_4	50	35	II 5 639.7	..	100
2 262.5	40	25	2 682.8	50	35	5 730.5	12	..
2 270.1	25	15	2 692.3S_7	40	40	II 6 004.6	..	200
2 289.0	20	10	2 718.9C	50	50	6 079.6	20	100
2 293.5	25	10	2 727.2	30	30	II 6 130.0	10	150
2 306.5S_1	35	30	2 769.9N_5C	100	70	7 844.4	100	..
I 2 311.5p*S_2N_1	150R	50	2 851.1	50	45	7 924.7	300	..
2 315.9	20	9	I 2 877.9§N_6C	250	150	7 969.6	50	..
2 360.5	20	5	3 011.1	..	70			

Control lines:	Interfering lines:
*Cd 2144.4	*Co Fe Mo V
Co 2307.9	
Ni 2320.1	
†Co 2521.4	†Au Ba Pb Si Co Mo V W
Fe 2522.9	
Si 2506.9	

Control lines:	Interfering lines:
‡Fe 2483.3	‡Ag Pb Cr Fe Mn W
Fe 2611.9	
§Cr 2865.1	§Cu Cr Ir Pd Pt V
Ga 2943.6	Mo Ca Te
Si 2516.1	

Control lines:	
B Cu	3274.0
	3268.3
S_1Pb	2322.0
S_2Pb	2399.6
	2388.8
	2332.5
S_3Pb	2388.8
S_4Pb	2657.2
	2562.4
S_5Pb	2657.2
	2628.3
S_6Pb	2657.2
S_7Pb	2657.2
S_8Pb	3043.9
S_9Pb	3043.9
S_{10}Pb	3220.5

Control lines:	
N_1Sn	2359.7
	2282.2
	2333.0
	2282.2
Sn	2368.2
	2317.2
Pb	2399.6
	2388.8
	2332.5
N_2Sn	2523.9
	2455.9
	2433.5
	2531.1
	2571.6
Sn	2546.6
Pb	2428.6

Control lines:	
N_3Sn	2637.0
	2594.4
	2368.2
	2558.1
Sn	2571.6
Pb	2657.2
	2562.4
	2628.3
N_4Sn	2637.0
Pb	2657.2
N_5Sn	2761.8
Pb	2657.2
N_6Sn	2761.8
N_7Pb	3034.9
N_8Sn	3223.6
	3218.7

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

ARSENIC

As

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 003.3	300R	10	I 3 075.3	60	35	II 4 602.7	..	200
I 2 009.2	50R	8	II 3 116.6	..	150	4 607.5	..	200
2 031.4	..	75	I 3 119.6	100	50	4 627.8	..	200
I 2 047.6	25	3	II 3 749.8	..	100	II 4 630.1	..	200
I 2 113.0	50	5	II 3 842.8	..	50	II 4 707.8	..	200
I 2 144.1	50R	..	II 3 948.7	..	50	II 4 730.9	..	125
I 2 133.8	18	..	II 4 006.3	..	50	II 4 888.7	..	50
I 2 165.5	50R	3	4 119.9	..	50	II 4 985.6	..	50
I 2 271.4	25	1	4 243.3	..	100	II 5 105.8	..	150
I 2 288.1p*LS$_1$	250R	5	II 4 315.9	..	50	II 5 107.8	..	150
I 2 344.0	25	..	II 4 324.1	..	50	II 5 231.5	..	60
I 2 349.8p*LS$_2$C	250R	18	II 4 336.9	..	100	II 5 331.5	..	200
I 2 369.7	40R	20	II 4 352.3	..	200	II 5 398.0	..	200
I 2 370.8S$_3$	50R	3	II 4 353.0	..	100	II 5 498.0	..	200
I 2 381.2	75	4	II 4 371.4	..	50	II 5 558.3	..	200
I 2 437.2	25	2	II 4 413.6	..	50	II 5 651.5	..	200
I 2 456.5	100R	8	II 4 431.7	..	200	II 5 657.2	..	60
I 2 492.9C	25	5	II 4 466.6	..	80	5 685.7	..	60
I 2 745.0S$_4$C	8R	8	4 474.6	..	200	II 6 022.8	1	150
I 2 780.2p†LC	75R	75	II 4 494.6	..	200	II 6 110.3	..	150
I 2 860.5‡C	50R	50	II 4 540.0	..	200	II 6 110.6	..	150
I 2 898.7C	25R	40	4 543.8	..	200	II 6 170.5	..	150
2 959.7	..	75	II 4 549.2	..	125	I 7 960.3	25	..
I 3 032.8	125	70	II 4 552.4	..	50			

Control lines:	Interfering lines:	Control lines:
*Be 3130.4	*Be Fe Mo Ti V W	Cr 2858.7
†Fe 2772.1	†Au Bi Cr Co Ga Mg Mn Mo Pb Sn Ti Zn W	Cr 2862.6
Mg 2802.7		S$_1$Pb 2242.5
Mg 2790.8		2332.5
Mo 2775.4		S$_2$Pb 2332.5
‡Cr 2865.1	‡Mo Pt Ti	S$_3$Pb 2399.6
		S$_4$Pb 2628.3

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

BARIUM

Ba

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spar
II 2 245.6	12	12	4 350.4	40	20	I 5 777.7p	500R	100
II 2 254.7	10	10	4 359.6	15	3	I 5 800.3	100	20
II 2 304.2	60R	80R	4 402.6	80	10	5 805.7	70	....
II 2 335.3	60R	100R	4 406.8	20	....	I 5 826.3	150	....
2 347.6	30	40	4 413.7	10	3	5 853.7	300	100
I 2 373.1	12	2	4 431.9	60	30	5 907.7	20	....
II 2 528.5	....	50R	4 467.1	20	3	I 5 971.7	150	50
I 2 596.7	40	....	I 4 489.0	80	3	5 972.8	100	....
II 2 634.8	30	50	I 4 493.6	60	5	I 5 997.1	150	50
II 2 647.3	10	40	4 505.9	60	20	I 6 019.5	150	50
I 2 702.6	50	5	4 523.2	60	10	I 6 063.1	200	60
II 2 771.4	12	8	II 4 524.9	80	30	6 083.4	10	3
I 2 785.3	50	....	II 4 554.0P*LAC	1000R	200	I 6 110.8	200	60
I 3 071.6‡C	100R	50R	4 573.9	50	20	6 140.4	10	....
I 3 222.2	20	....	4 579.7	75	40	6 141.7	2000	2000
I 3 262.0	40	....	4 591.8	15	3	6 233.6	18	3
I 3 281.5	25	....	4 599.8	50	10	6 341.7	90	50
3 315.8	10	....	4 605.0	10	3	6 446.9	20R	15
I 3 322.9	30R	....	I 4 620.0	25	....	6 450.9	100	20
I 3 356.9	40R	3	4 628.3	40	4	6 482.9	100	50
I 3 377.0	15R	6	4 636.3	20	....	6 496.9	800R	300
I 3 501.1C	1000	20	4 673.6	40	5	6 498.8	60	20
I 3 525.0	20	5	4 691.6	100	40	6 527.3	200	20
I 3 544.7	20	5	I 4 700.4	25	3	I 6 595.3	1000	300
I 3 547.8	10	6	I 4 726.5	80	30	I 6 654.1	50	....
I 3 579.7	10	8	I 4 877.7	30	8	I 6 675.3	500	100
I 3 599.4	10	8	II 4 900.0	30	200	I 6 693.9	600	100
3 611.0	10	3	I 4 902.9	15	3	I 6 771.9	60	....
3 630.6	15	5	II 4 934.1C	400	400	I 6 865.7	200	....
3 636.9	18	4	II 5 013.1	....	50	I 6 867.9	100	....
3 662.5	10	5	5 055.0	12	2	I 7 060.0	2000	....
3 889.3	10	2	5 159.9	50	10	I 7 090.0	100	....
II 3 891.8	18	25	5 175.6	10	7	I 7 120.3	800	....
I 3 909.9	50R	20R	I 5 267.0	25	12	7 126.6	10	....
I 3 935.7	80R	30R	5 277.6	10	....	I 7 153.6	80	....
I 3 937.9	12	10	5 294.1	10	....	I 7 195.2	200	....
I 3 975.4	10R	....	5 302.8	20	5	I 7 208.1	20	....
I 3 993.4	100R	50R	5 309.0	10	....	I 7 213.6	10	....
I 3 995.7	18	5	5 404.9	15	....	I 7 228.8	200	....
II 4 130.7	50R	60	I 5 424.6	100R	30R	I 7 280.3	1000	....
4 132.4	10	4	5 425.6	10	....	I 7 307.2	10	....
II 4 166.0	12	50	5 473.7	10	....	I 7 326.5	10	....
I 4 239.6	10	4	I 5 519.1	200R	60R	I 7 359.3	20	....
4 242.6	10	5	I 5 535.6P†FC	1000R	200R	I 7 375.5	50	....
I 4 264.4	15	4	5 593.3	12	....	I 7 392.4	400	....
4 283.1	25	20	5 618.7	10	....	I 7 410.0	30	....
4 323 0	15	5	5 619.1	10	3	I 7 417 5	100	....
4 324 2	15	3	5 680.2	60	....	I 7 459 8	300	....
I 4 332 9	20	3	5 713.6	10	....	I 7 476 2	30	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

BARIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 7 488.1	200	....	I 7 672.0	400	....	I 7 780.4	300	....
I 7 523.6	15	....	I 7 706.5	25	....	I 7 839.5	15	....
I 7 528.2	15	....	I 7 621.9	10	....	I 7 878.0	20	....
I 7 543.4	15	....	I 7 672.0	400	....	I 7 905.7	300	....
7 583.8	10	....	I 7 751.7	40	....	I 7 911.3	200	....
I 7 610.5	60	....	I 7 766.9	15	....	I 7 961.3	15	....
I 7 636.9	40	....	I 7 775.3	25	....	I 7 982.4	20	....
I 7 642.9	100	....						

Control lines:
*Be 4535.5
Mo 4558.5
Ni 4551.3
Ti 4552.5
ALa 4558.5

Interfering lines:
*Al Be Co Cr Cs Cu Fe Mn
Mo Ni Pb Pt Si Ti V W
Ru Ce Ta

‡Ce Pt Co Zn Ca Cb Mo Cr

Control lines:
†Mo 5506.5

Interfering lines:
†Al Be Bi Ca Co Cu Fe Mg
Mn Mo Na Ni Pb Sb Sr
Ti V W Ce Rh

BERYLLIUM

Be

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 056.5	100	....	I 3 019.3	30	....	I 3 455.2	20	....
I 2 175.1	25	3	I 3 019.5	15	....	I 3 515.5	30	....
I 2 348.6P*C	2000R	50	II 3 046.7	10	....	I 3 736.3	10	....
I 2 350.7	25	2	I 3 110.8	20	....	I 3 813.4	50	....
I 2 494.5	30	....	I 3 111.0	15	....	I 3 865.4	30	....
I 2 494.6	25	....	II 3 130.4P†LC	200	200	I 3 865.5	10	....
I 2 494.7	30	....	II 3 131.1LB$_2$‡C	200	150	4 364.0	....	50
I 2 650.5B$_1$	100	15	I 3 229.7	15	....	I 4 407.9	20	....
I 2 650.6	30	....	II 3 274.6	....	50	I 4 572.7	15	15
I 2 650.6	20	15	I 3 321.0	50	....	4 672.2	....	100
I 2 650.6	25	....	I 3 321.1	100	15	II 4 673.5	....	100
I 2 650.7	10	....	I 3 321.3p	1000R	30	5 272.7	....	20
I 2 650.8	25	....	I 3 367.6	25	....	5 907.7	20	....

Control lines:
*Fe 2364.8
Fe 2388.6
†Cr 2849.8
Hg 3650.2

Interfering lines:
*Al As Bi Fe Ni Os Pt Cu
Zr Ir W Ba
†Ag Cr Hg Mn Os V W Ba
Ta U Cb Ce
‡Cr Hg Ce Th Ti Rh

Control lines:
B_1Mn 2939.3
B_2Bi 3067.7

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

BISMUTH

Bi

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 021.2	40	15	2 532.6	25	....	3 846.0	....	100
2 024.0	50	....	2 582.1	35	5	3 864.2	....	150
2 042.0	100	15	I 2 627.9G_1N_1	200	200	I 3 888.2	40	2
2 049.7	25	20	2 696.6	100	100	II 4 079.2	2	40
I 2 057.7	40	....	I 2 696.8G_2	25R	15R	I 4 121.5S_5	125	50
I 2 061.7p	300R	100	I 2 730.5S_3G_3	200	100	II 4 259.6	....	60
2 064.8	50	4	I 2 780.5pG_4	200	100	II 4 302.1	2	50
I 2 110.3	250R	50	I 2 798.7	200	25	I 4 308.2	50	12
I 2 133.6	100	40	I 2 809.6p	200	100	II 4 340.6	....	40
I 2 134.3	100R	5	I 2 863.8	80	18	II 4 379.4	25	20
II 2 143.4	....	12	I 2 898.0p*N_2G_5C	500R	500R	4 561.2	....	10
2 152.9	50R	....	I 2 938.4p$B_1S_4N_3$C	300	300	II 4 705.4	....	50
2 153.5	40	....	I 2 989.0pS_5N_4	250	100	I 4 722.2	10	5
2 156.9	75R	....	I 2 993.3	200	100	I 4 722.6N_6	1000	100
2 164.1	20	2	I 3 024.6$B_2S_6G_6$C	250	50	I 4 722.8	10	5
I 2 176.6	20	4	3 034.9	30	30	II 5 124.3	....	100
I 2 189.6	25	5	I 3 035.2	60	....	II 5 144.5	2	300
2 203.1	20	....	I 3 067.7P†LS_7A	3000R	2000	II 5 208.8	5	70
I 2 228.3	100R	50	G_7N_5C			II 5 209.3	....	600
I 2 230.6S_1	100R	....	I 3 076.7	20	18	5 552.4	500	100
I 2 276.6p	100R	40	3 115.4	....	500	5 742.6	30	10
2 309.7	18	....	3 302.6	150	....	II 6 128.1	....	30
I 2 400.9S_2	200R	100	I 3 397.2B_3	100	50	I 6 134.8	50	30
I 2 430.5	30	6	I 3 405.7	60	....	II 6 497.6	2	12
2 433.4	30	....	II 3 455.3	....	100	II 6 600.2	....	70
I 2 448.1	50	8	I 3 510.9B_4	200	30	II 6 808.6	....	70
2 499.5	25	12	I 3 596.1	150	50	6 991.1	10	....
I 2 515.7	100	25	3 695.6	....	50	7 838.7	400	....
I 2 524.5	100	25	3 792.8	....	500	7 975.9	30	....

Control lines:
*As 2745.0
Mo 2911.9
V 2903.1
W 2947.0

Interfering lines:
*As Be Co Cr Ti V Mn
Ir Fe Pt Cb Mo

Control lines:
†Fe 3057.5
Ti 3078.6
V 3073.8
V 3185.4

Interfering lines:
†Fe Mo V W Th Sn Rh Cr

Control lines:
B_1Sn 2863.3
B_2Sn 2850.6
B_3Cu 4275.1
Pb 3683.5
B_4Pb 3739.9
S_1Pb 2253.9
S_2Pb 2400.9
S_3Pb 2657.2
S_4Pb 2926.8
S_5Pb 2980.3
S_6Pb 3220.5
3240.2
S_7Pb 3221.7

Control lines:
G_3Pb 2657.2
G_4Pb 2657.2
G_5Sn 3141.8
2863.3
G_6Pb 3220.5
G_7Sn 3009.1
3141.8
3218.7
3223.7
Pb 3220.5
N_1Sn 2637.0
N_2Sn 2850.6
2671.8

Control lines:
2980.2
2973.0
N_5Sn 3223.6
3218.7
3175.0
3141.8
3034.1
3009.1
2913.3
Pb 3262.4
3240.2
3220.5
3176.5

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

BISMUTH (*Continued*)

Control lines:
3119.1
3043.9
3040.2
2657.2
S_8Pb 3786.3
S_9Pb 4168.0
G_1Sn 2637.0
G_2Sn 2765.0
APb 3224.5

Control lines:
Pb 3043.9
2966.4
N_3Pb 3043.9
2966.4
N_4Sn 2896.0
2850.6
2761.8
Pb 3043.9

Control lines:
3043.9
3119.2
2980.2
2973.0
Cu 3140.3
3108.6
N_6Sn 4524.7

BORON

B

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 088.9	100	15	I 2 497.7P*XC	500	400	II 3 179.4	5	100
I 2 089.6	150	20	2 514.4	....	50	II 3 451.4	....	100
I 2 496.8†C	300	300	2 779.3	....	100			

Control lines:
*Fe 2533.8

Interfering lines:
*Fe Mo V Sn W
†Fe W Mo Sn Ta

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

CADMIUM

Cd

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 144.4PN_1	50	200R	I 2 862.3	15	10	I 3 649.6	20	15
2 194.6	5	100	I 2 868.3	100	80	I 3 729.1	15R	....
2 239.9	80	30	I 2 880.8	200R	125	4 414.6	....	200
II 2 265.0P*LN_2	25	300	I 2 881.2C	50R	[30]	I 4 678.2S_4N_8	200	200
2 267.5	20	30	II 2 929.3	....	50	I 4 799.9‖S_5N_9C	300	300
I 2 288.0 {P†LG_1	1500R	300R	I 2 961.5	20	15	I 5 085.8S_6C	1000	500
{N_3C			I 2 980.6C	1000R	500	II 5 378.0	5	50
2 306.6	20	30	I 2 981.3	200R	[40]	I 6 031.4	30	....
2 312.8S_1N_4	1	200	I 2 981.9	50	[10]	I 6 099.2	300	....
II 2 321.2N_5	....	100	I 3 005.4	25	4	I 6 111.5	100	....
2 329.3	50	60	I 3 080.8	150	100	I 6 116.2	50	....
I 2 544.7	50	....	I 3 082.7	30	....	I 6 325.2	100	....
I 2 580.3	50	....	I 3 133.2	200	300	I 6 330.0	30	....
I 2 629.1	50	10	II 3 250.2	....	100	II 6 359.9	10	50
I 2 639.5	75	15	I 3 252.5	300	200	I 6 438.4696¶	2000	1000
I 2 660.4	50	....	I 3 261.1C	300	300	II 6 465.0	5	50
I 2 677.6	100	25	I 3 403.6pG_2N_6C	800	500	II 6 725.8	....	100
I 2 712.6	75	20	I 3 466.2 {pG_3N_7			I 6 778.1	30	....
I 2 733.9	50	25	{A_3C	1000	500	I 7 132.3	30	....
II 2 748.6A_2	5	200	I 3 467.7G_4	800	400	I 7 346.2	1000	....
I 2 756.8	50	....	I 3 500.0	25	15	7 383.9	1000	....
I 2 763.9	100	50	I 3 610.5 {p§S_3	1000	500	I 7 385.3	800	....
2 764.1	50	25	{G_5C			7 393.0	70	....
I 2 775.0	50	20	I 3 612.9	800	500	I 7 399.2	70	....
I 2 836.9	200	80	I 3 614.5G_6	60	100			

Control lines:		Interfering lines:	Control lines:		Interfering lines:
*Al	2269.1	*Fe Os	§Fe	3618.8	§Al Ba Cr Cs Cu Mn Fe Ce
Ni	2270.4		Mo	3447.1	Ni Pt Ti V
†As	2349.8	†As Au Fe Mo Pt Ni Ir Co W	Ni	3510.3	
‡In	3256.1	‡Co Fe In Mo	‖Os	4394.9	‖Ag Al As Be Co
Sn	3034.1	V W Ti Ce CA B			K Mo Ni Ra
Ti	3242.0	¶Ca Co Mn y			

Control lines:
S_1Pb 2322
S_3Pb 3671.5
S_4Pb 5005.5
5042.8
S_5Pb 5005.5
5042.8
S_6Pb 5042.8
G_1Sn 2282
G_2Sn 3331
3656
3142
3219
G_3Sn 3656
3219
3224
G_4Sn 3656
3219
3224
G_5Sn 3656
G_6Sn 3656

Control lines:
N_1Sn 2199.3
N_2Sn 2282.2
2267.2
2268.9
2317.2
Pb 2243
2253.9
N_3Sn 2380.7
2333
2286.7
2231.7
2282.2
2286.7
Sn 2317.2
Pb 2332.5
2249
2243
3043.9
N_4Sn 2317.2

Control lines:
Pb 2332.5
N_5Sn 2251.2
N_6Sn 3223.6
3218.7
3352.3
3240.2
N_7Sn 3655.9
3223.6
3218.7
3330.6
Pb 3240.2
3119.2
N_8Pb 5005.5
N_9Pb 5005.5
A_1Zn 2064
2265
A_2Pb 2628
A_3Pb 2628
Zn 2684

¶ Cd line 6438.4696 is the primary wavelength standard.

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

CALCIUM

Ca

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 103.2	10	25	I 3 630.7	150	9	I 4 578.6	80	5
II 2 112.8	10	25	I 3 630.9C	10	....	I 4 581.4	100	10
I 2 150.8	10	....	I 3 644.4C	200	15	I 4 585.9	125	10
II 2 197.8	20	40	I 3 644.8C	30	....	I 4 685.3	25	1
I 2 200.7	20	....	I 3 675.3	10	2	I 4 878.1	100	10
II 2 208.6	20	50	I 3 678.2	15	2	5 021.2	10	....
I 2 275.5	40	5	II 3 706.0	15	40	I 5 041.6	30	....
I 2 398.6	100R	20	II 3 736.9	12	50	I 5 188.9	50	6
II 2 573.1	3	150	I 3 748.4	12	....	I 5 261.7	20	6
I 2 680.4	15	....	I 3 750.3	20	3	I 5 262.2	20	8
I 2 721.6	20	2	I 3 753.4	30	3	I 5 264.2	15	8
I 2 995.0	25	3	I 3 870.5	15	....	I 5 265.6	20	10
2 997.3	25	5	I 3 872.6	30	....	I 5 270.3	20	10
I 2 999.6	20	10	I 3 875.8	50	....	5 272.0	10	....
3 000.9	20	6	II 3 933.7p*LC	600R	600R	I 5 349.5	12	12
I 3 006.9X_2X_3	25	5	I 3 948.9	40	15	I 5 582.0	20	12
I 3 009.2	20	5	I 3 957.1	80	3	I 5 588.7	35	25
I 3 080.8	20	2	II 3 968.5p†LX_1C	500R	500R	I 5 590.1	15	10
I 3 095.3	10	2	I 3 972.6	12	....	I 5 594.5	35	20
I 3 108.6	30	3	I 3 973.7	200	15	I 5 598.5	35	20
3 117.7	10	2	4 030.3	10	2	I 5 601.3	15	10
I 3 136.0	15	3	I 4 092.6	15	2	I 5 602.8	15	10
I 3 140.8	15	3	I 4 094.9	15	7	I 5 857.5	40	30
I 3 150.7	50	2	I 4 098.5	15	3	I 6 102.7	80	50
I 3 158.9L	100	300	I 4 226.7‡FB_1C	500R	50R	I 6 122.2	100	100
I 3 169.9	10	2	I 4 240.5	10	10	I 6 161.3	10	6
II 3 179.3LC	100	400	I 4 283.0	40	20	I 6 162.2	40	45
I 3 180.5	20	....	I 4 289.4	35	20	I 6 163.8	10	7
I 3 209.9	30	2	I 4 299.0	30	18	I 6 166.4	15	5
I 3 215.1	20	4	I 4 302.5	50	25	I 6 169.1	25	15
I 3 225.9	80	10	I 4 307.7	45	20	I 6 169.6	40	20
I 3 269.1	10	2	I 4 318.7	60	20	I 6 439.1	150	50
I 3 274.7	20	....	I 4 355.1	50	....	I 6 449.8	60	12
I 3 286.1	30	2	4 374.6	10	2	I 6 462.6	125	50
I 3 344.5	100	7	I 4 425.4p	100	20	6 471.7	40	15
I 3 350.2C	100	10	I 4 435.0p	150	25	I 6 493.8	80	30
I 3 350.4C	15	3	I 4 435.7	100	15	I 6 499.7	30	15
I 3 361.9C	125	10	I 4 454.8p	200	5	I 6 572.8	50	....
I 3 362.1	15	5	I 4 455.9	100	75	I 7 148.1	500	....
I 3 468.5	20	3	I 4 456.6	20	15	I 7 202.2	30	....
I 3 474.8	40	5	I 4 512.3	10	....	I 7 203.2	200	....
I 3 487.6	100	2	I 4 526.9	100	3	I 7 326.1	400	....
I 3 624.1	150	15						

Control lines:	Interfering lines:
*Co 3929.3	*Ba Co Fe Mn Mo Sc Ce Ir V
Fe 3899.7	Ag
†Cr 3963.7	†Al Co Cr Fe Mo Ni Ir Ce Th Y Zr Ag V S B Y Th Rh Tr Cr Ag

Control lines:	Interfering lines:
Fe 3930.3	
‡Co 4248.2	‡Co Cr Fe Ge Mn Mo Ce Ir W
Fe 4236.0	
x_1Mo 3903	
x_2Mo 3158	
x_3Mo 3208	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

CARBON

C

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 478.6P*C	400	....	II 3 876.7	....	40	I 5 793.5	30	....
II 2 509.1	....	200	II 3 920.7	....	200	II 6 578.0	....	500
II 2 511.7	....	60	II 4 074.5	....	50	II 6 582.9	....	200
II 2 512.0	....	400	II 4 076.0	....	80	II 6 783.8	....	100
II 2 836.7	....	200	II 4 267.0	....	350	I 7 118.5	20	....
II 2 837.6	....	40	II 4 267.3	....	500	II 7 231.1	....	100
II 3 876.2	....	125	II 5 145.2	....	70	II 7 236.2	....	150
II 3 876.4	....	60						

Control lines:
*Fe 2470.7

Interfering lines:
*Hg Sb Ta V Cr

Control lines:
W 2481.5

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

CERIUM

Ce

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 180.7	....	100	3 815.8	50	5	4 527.3	50	25
2 222.0	....	100	I 3 853.2	25	3	4 528.5	30	15
2 225.1	....	100	3 890.0	50	8	4 562.4	40	40
2 242.3	....	60	3 898.3	80	6	4 572.3L	35	35
2 350.2	....	50	3 918.3	60	6	4 593.9	30	30
2 372.4	....	50	3 933.7	60	60	4 882.5	30	....
2 380.2	....	50	3 942.7	50	20	5 044.0	25	1
2 651.0	25	2	II 3 952.5	60	30	5 079.7	30	....
2 833.3	50	....	3 978.9	50	50	5 187.5	50	....
2 837.3	50	....	II 3 992.4	50	8	5 191.7	30	....
2 852.1	50	1	3 993.8	50	6	5 211.9	50	....
3 063.0	40	10	II 3 999.2	80	20	5 274.2	50	3
II 3 146.4	30	....	I 4 012.4P	60	20	5 330.5	25	....
3 194.8	25	....	II 4 014.9	60	12	5 353.5	50	3
3 201.7	50	10	II 4 040.8P	70	5	5 393.4	30	....
3 218.9	50	8	4 073.5	50	8	5 409.2	50	....
II 3 221.2	50	8	4 083.2	35	6	5 472.3	25	....
II 3 234.2	40	8	4 133.8‡	35	8	5 512.1	50	....
3 272.3	40	15	4 137.6S	25	12	5 523.0	100	....
II 3 285.2	35	5	4 152.0	30	8	5 556.3	35	....
3 304.8	30	3	4 165.6	40	6	5 601.3	50	....
3 343.9	50	6	II 4 186.6P‖C	80	25	5 655.1	40	....
II 3 344.8	50	8	4 222.6	80	18	5 670.0	50	....
3 377.1	50	5	4 226.7	50	30	5 677.7	25	....
3 426.2	30	6	4 248.7	60	8	5 697.0	40	....
II 3 442.4	25	3	4 255.8	40	6	5 699.2	40	....
3 476.8	35	10	4 289.9	50	25	5 719.0	40	....
3 485.1	30	10	4 296.7	40	25	5 743.5	25	....
3 488.6	35	5	4 306.7	30	15	5 773.1	30	....
3 517.4	40	6	II 4 320.7	50	8	5 788.1	25	....
II 3 539.1	100	10	II 4 330.4	50	5	5 804.4	25	....
3 560.8*	300	2	I 4 337.8	25	10	5 812.9	40	....
3 577.5	300	12	II 4 349.8	40	5	5 862.5	25	....
3 590.6	50	1	4 382.2	40	12	5 928.3	25	....
I 3 623.8	60	5	4 391.7	40	15	5 940.9	40	....
I 3 655.9	25	12	4 418.7	40	10	6 013.4	25	....
3 668.0	80	15	4 449.3	50	8	6 024.2	50	....
3 709.3	25	....	4 460.2	60	20	6 043.4	30	....
3 801.5†	25	3	4 471.2	35	8	6 458.1	25	....

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Co 3533.4	*Co Cr Fe Hg Os	§Os 4260.9	§Co Fe Mn Mo Ni Pt
†Fe 3795.0	†Co Cr Fe Hg Mn Sn Ti W	‖Fe 4187.1	‖Co Cr Fe Mn Mo Ni U Ce Ti W
‡Fe 4123.8	‡Ba Co Cr Fe Li Mn Sb Se Ti		

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

CESIUM

Cs

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 3 347.4	30	....	I 6 034.1	35	....	I 7 280.0	35	....
I 3 476.9	100	....	I 6 212.9	100	....	7 609.0	500	....
I 3 480.1	50	....	6 586.0	35	....	7 944.1	800	....
I 3 611.5	200	....	I 6 586.5	500	....	7 990.7	100	....
I 3 617.4	60	....	I 6 628.7	35	12	I 8 015.7	200	....
I 3 876.4	300	....	6 723.3	500	6	I 8 078.9	100	....
I 3 888.7	150	10	I 6 870.5	200	....	I 8 079.0	1000	....
I 4 555.4p*FC	2000R	100	6 973.3	500	....	I 8 521.1P	5000R	....
I 4 593.2p†C	1000R	50R	I 6 983.5	25	....	I 8 761.4	500	....
I 6 010.3	50	....	7 228.5	500	....	I 8 943.5	2000R	....

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Be 4535.5	*Al Ba Be Co Cr Cu Fe	†Al 4576	†Al Ba Be Co Cr Fe Li Ce V
Ti 4552.5	Mo Ni Pb Pt Si Ti Zr U	V 4395.2	Mo Ni Pd Sb Sc Mn W
Ti 4522.8			

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

CHROMIUM

Cr

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 039.3	25	....	I 2 519.5	150R	6	II 2 750.7	30	150
II 2 055.5	100	300	I 2 528.0	35	1	I 2 751.6	30	....
II 2 061.5	100	200	I 2 528.2	30	....	II 2 751.9	20	125
II 2 065.4	50	150	I 2 530.4	35	1	I 2 752.9	300R	40
2 117.6	....	50	2 538.3	....	25	2 754.3	3	50
2 235.9	....	50	I 2 541.4	60	3	2 755.4	50	2
2 256.1	....	50	I 2 549.5	25	2	2 756.3	1	100
2 297.2	10	50	I 2 553.1	20	1	I 2 757.1	300R	10
2 314.7	8	50	I 2 557.2	35	2	II 2 757.7	35	150
2 324.9	....	50	I 2 560.7	30	15	I 2 761.8	300R	35
2 345.3	8	60	I 2 571.7	50R	35	II 2 762.6	40	100
I 2 362.2	25	2	I 2 577.7	35	3	2 763.1	35	4
I 2 364.7	20	8	I 2 591.8	100R	12	I 2 764.4	200R	6
I 2 366.0	25	8	I 2 603.6	30	1	II 2 766.5	40	300R
I 2 366.3	15	3	2 622.9	25	2	2 767.4	30	8
I 2 366.9	60	60	2 639.4	30	....	2 768.6	1	60
I 2 367.9	20	....	2 642.1	35	3	I 2 769.9	400R	40
I 2 368.5	30	2	II 2 671.8	30	15	2 774.4	....	100
I 2 370.4	40	3	II 2 677.2	35	300R	2 775.7	30	....
2 372.9	40	3	II 2 678.8	10	80	2 777.7	40	1
I 2 373.7	60	....	II 2 687.1	30	60	2 778.1	12	60
I 2 383.3	20	....	I 2 688.0	30	....	2 779.1	20	5
I 2 385.7	25	....	I 2 690.3	30	....	2 780.3	....	100
I 2 386.2	20	....	II 2 691.0	35	125	I 2 780.7	600R	15
I 2 386.8	20	....	2 696.5	30	1	2 785.7	5	80
I 2 389.5	25	....	I 2 700.6	30	2	2 792.2	5	80
I 2 392.4	25	2	I 2 702.0	35	8	2 795.8	35	3
I 2 392.9	40	2	I 2 703.5	15	....	2 800.8	12	150
2 394.0	....	50	2 703.6	....	50	2 812.0	8	80
I 2 395.8	25	2	2 709.3	2	60	2 814.5	15	2
I 2 396.4	30	3	2 710.2	50	....	2 818.4	8	80
I 2 399.1	50	2	2 710.9	1	70	2 820.8	20	1
I 2 399.6	40	....	II 2 712.3	30	70	2 822.0	10	80
I 2 408.6	150R	2R	I 2 716.2	20	4	2 822.4	20	100
I 2 408.7	40	1	II 2 722.7	30	80	2 826.7	70	3
2 474.1	35	....	I 2 726.5	300R	40	2 830.5	15	80
2 479.1	20	....	2 727.3	4	70	II 2 835.6PC	100	400R
I 2 491.3	30	1	I 2 731.9	300R	30	2 838.8	3	80
I 2 492.6	50	....	I 2 736.5	300R	50	2 840.0	25	125
I 2 495.1	35	....	2 739.4	35	25	II 2 843.3PC	125	400R
I 2 496.3	125R	2	II 2 740.1	20	60	2 846.0	25	4
I 2 499.8	20	....	2 741.1	35	30	2 849.3	35	30
2 502.5	100R	3	II 2 742.0	15	50	II 2 849.8PC	80	150R
I 2 504.3	150R	3	2 742.2	30	3	2 851.4	20	80
I 2 508.1	35	1	I 2 722.3	25	25	2 853.2	5	100R
I 2 509.0	25	1	I 2 742.2	50	50	2 855.1	4	100
2 512.0	25	1	II 2 743.6	30	125	II 2 855.7P	60	200
I 2 513.6	20	2	I 2 748.3	300	5	II 2 856.8	20	60
I 2 516.9	35	2	II 2 749.0	35	200	II 2 857.4	20	80

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

CHROMIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 858.9	50	80	I 2 988.6	200R	150	3 107.6	2	125
II 2 860.9	60	100	2 989.2	10	90	3 109.3	30	12
II 2 862.6	80	300R	I 2 991.9	125R	60	3 110.9	25	8
II 2 865.1	60	200R	I 2 994.1	150	50	II 3 118.7	35	200
II 2 866.7	80	125R	I 2 995.1	200R	75	3 119.7	30	6
2 867.1	20	35	I 2 996.7	300R	125	II 3 120.4	40	150
II 2 870.4	25	300	I 2 998.9	200R	70	II 3 122.6	10	80
2 871.5	....	80	I 3 000.9	150R	125	II 3 124.8	20	125
I 2 871.6	50	2	3 003.9	1	150	II 3 125.0	20	125
2 873.2	25	....	I 3 005.1	300R	125	II 3 128.7	30	150
II 2 873.5	30	125	I 3013.0	80	40	3 131.2	20	6
II 2 873.8	20	40	I 3 013.7	200R	150	II 3 132.1	25	125
II 2 876.0	30	80	I 3 014.8	300R	100	3 132.8	20	2
II 2 876.2	25	80	I 3 014.9	300R	100	II 3 134.3	3	50
II 2 878.0	30	100	I 3 015.2C	200R	80	3 136.7	20	50
2 878.4	20	80	3 015.5C	1	150	3 144.4	50	12
I 2 879.3	60	12	I 3 017.6C	300R	200	3 145.6	20	1
II 2 880.9	20	25	I 3 018.5	200R	125	II 3 147.2	25	15
2 881.1	25	2	I 3 018.8	200R	60	3 148.4	30	15
I 2 887.0	100	18	I 3 020.7	200R	100	3 150.1	6	50
I 2 889.3	60R	30	I 3 021.6C	300R	200R	3 155.1	30	25
2 890.2	20	....	I 3 024.4	300R	125	3 159.6	60	20
2 891.4	30	15	3 026.6	8	125	3 162.4	25	....
I 2 893.3	80R	10	3 028.1	2	125	3 163.8	40	25
2 894.2	40	2	I 3 029.2	70	50	3 169.2	2	50
I 2 896.8	60R	30	I 3 030.2	200R	150	I 3 169.6	25	2
I 2 899.2	50	25	I 3 031.4	40	30	3 172.1	2	200
2 904.7	20	2	II 3 032.9	10	100	3 179.2	100	10
I 2 905.5	60R	8	I 3 034.2	200R	60	II 3 180.7	30	150
I 2 909.1	60R	12	I 3 037.0	200R	100	3 183.3	6	150
2 910.7	....	50	I 3 039.8	80	35	3 188.0	150	60
I 2 910.9	60R	8	I 3 040.8	500R	200	I 3 192.1	30	2
I 2 911.1	40	8	3 041.7	2	125	II 3 197.1	35	30
2 913.7	60R	5	II 3 042.8	1	100	3 198.1	40	10
II 2 921.8	4	60	3 043.9	....	50	3 201.3	1	50
2 927.1	2	80	3 047.5	25	6	II 3 208.5	20	40
2 930.9	....	50	I 3 039.9	20R	....	II 3 209.2	40	125
2 934.5	25	....	3 050.1	10	150	3 211.3	35	12
2 953.4	4	50	3 052.2	20	10	3 216.6	3	125
2 961.7	10	60	I 3 053.9	3R	150	3 217.4	30	20
2 966.1	2	70	II 3 059.5	8	60	3 218.7	80	2
I 2 967.6	60R	30	I 3 061.7	20	3	I 3 226.6	30	1
I 2 971.1	80R	15	3 065.1	20	50	3 229.2	35	....
2 971.9	8	30	II 3 067.2	25	40	I 3 233.2	30	4
I 2 975.5	100R	50	3 073.7	35	25	3 234.1	10	150
2 979.7	10	60	I 3 077.8	25	125R	3 237.7	40	30
I 2 980.8	75R	50	3 093.5	1	100	3 238.1	30	20
2 985.3	10	60	3 095.9	125	3	3 238.5	25	8
I 2 985.8	25R	15	3 096.1	1	100	3 238.8	6	200
I 2 986.0C	25R	15	3 096.5	35	....	I 3 241.0	35	2
I 2 986.5C	125R	125	3 103.5	....	50	I 3 244.1	30	4

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

CHROMIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 245.5	20	15	3 346.7	150R	80R	3 411.1	80	3
3 247.3	20	1	II 3 347.8	35	125	II 3 421.2	50	200
3 251.6	30	....	3 349.1	125	40	II 3 422.7	35	125
3 251.8	35	....	3 349.3	35	50	3 426.0	25	2
3 253.3	20	1	3 351.6	35	8	3 427.7	40	1
3 254.9	50	....	I 3 352.0	50	50	3 431.3	35	8
3 257.8	40	30	3 353.0	20	30	3 432.0	25	4
3 258.8	....	50	3 353.1	15	50	3 432.3	25	6
3 260.0	50	30	3 353.6	30	....	II 3 433.3	30	150
3 264.3	6	50	3 356.4	35	....	I 3 433.6	50	35
I 3 266.6	35	4	3 356.7	35	....	I 3 434.1	30	25
3 270.7	50	1	3 357.4	6	125	I 3 435.7	20	12
3 272.0	60	....	II 3 358.5	40	200	3 435.8	30	12
3 286.4	20	1	3 359.2	25	....	I 3 436.2	50	50
3 291.0	30	....	3 360.1	20	....	3 439.4	30	2
3 291.8	10	200	II 3 360.3	50	200	I 3 441.1	30	25
3 293.8	30	1	II 3 361.8	10	100	I 3 441.4	80	90
II 3 295.4	10	200	I 3 362.2	80	8	3 443.8	30	25
3 298.3	30	8	I 3 362.7	40	....	3 445.6	100	80
3 302.2	50	1	3 365.5	25	2	I 3 447.0	35	25
3 302.9	30	2	I 3 367.5	50	....	I 3 447.4	35	35
I 3 304.3	30	....	II 3 368.1	35	125	I 3 447.7	35	30
3 305.2	25	....	3 370.2	30	1	3 450.8	25	4
I 3 307.8	40	8	3 374.6	25	2	I 3 453.3	35	35
3 309.8	30	2	3 374.9	25	4	I 3 453.7	30	25
3 310.6	2	200	3 376.2	25	....	3 455.0	....	100
II 3 311.9	6	125	3 376.4	30	20	3 455.3	35	10
II 3 312.2	5	125	II 3 378.3	25	150	3 455.6	50	35
3 314.6	10	100	I 3 379.2	40	6	3 457.6	4	125
I 3 316.5	20	10	3 379.4	6	100	3 458.1	35	15
3 318.1	80	....	3 382.1	30	1	I 3 460.4	40	30
3 321.2	20	1	II 3 382.7	35	200	3 464.8	30	3
3 323.3	25	....	I 3 384.2	35	....	3 465.3	35	30
II 3 325.1	20	20	I 3 384.6	40	1	3 465.6	30	8
3 324.3	10	60	3 385.3	30	2	I 3 467.0	50	20
3 326.6	40	18	3 386.5	30	2	3 467.7	50	30
II 3 328.4	20	40	I 3 388.7	40	4	3 468.8	30	8
I 3 329.1	30	6	3 390.8	30	3	I 3 469.6	50	15
3 330.6	80	....	II 3 391.4	4	150	I 3 470.4	30	8
3 332.9	30	10	II 3 393.0	10	100	I 3 470.5	25	6
3 333.6	125	3	II 3 393.8	15	125	I 3 471.5	30	3
3 334.7	150	....	3 394.3	15	150	3 472.1	....	80
II 3 336.3	18	80	3 395.6	2	100	I 3 472.8	30	8
II 3 339.8	25	150	3 399.5	1	60	3 472.9	30	8
3 341.4	50	1	II 3 402.4	25	80	I 3 473.6	35	10
II 3 342.6	30	125	II 3 403.3	30	200	3 474.4	35	8
I 3 343.3	30	10	3 403.6	35	3	I 3 474.9	35	3
3 343.7	30	....	3 407.3	50	1	I 3 477.2	25	5
3 344.5	20	2	3 408.0	40	1	I 3 478.8	35	3
3 345.2	15	2	II 3 408.8	35	100	I 3 479.1	30	1
3 346.0	35	35	3 409.4	60	1	I 3 479.3	35R	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

CHROMIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 3 480.3	30	1	3 679.1	15	5	I 3 849.5	20	20
3 481.5	30	30	3 679.8	40	8	I 3 850.0	40R	40R
3 486.5	20	4	I 3 686.8	20	5	I 3 852.2	60	12
3 488.5	35	10	II 3 712.9	12	125	I 3 853.2	20	10
3 495.0	35	25	3 716.5	20	6	I 3 854.2	40	15
3 502.3	35	6	I 3 730.8	60	12	3 854.8	20	15
3 503.9	20	....	I 3 732.0	50	15	I 3 855.3	35	35
3 510.5	40	8	I 3 43.0	25	10	I 3 855.6	30	30
II 3 511.8	20	50	I 3 743.6	40	40	I 3 856.3	20	15
3 527.1	30	5	I 3 743.9	40	40	I 3 857.6	50	25
I 3 550.6	70	60	I 3 744.5	30	12	I 3 858.9	35	20
3 555.8	20	6	I 3 748.6	40	30	3 862.5	25	20
II 3 556.1	20	4	I 3 749.0	125R	125R	I 3 870.3	80	3
3 558.5	20	....	I 3 757.2	50	30	I 3 874.5	70	12
3 562.3	20	12	I 3 757.7	50	50	I 3 879.2	60	15
3 564.7	20	8	I 3 758.0	50	35	I 3 881.2	60	18
3 566.2	80	12	3 767.4	20	10	I 3 881.9	50	6
I 3 572.7	25	5	I 3 768.2	60	60	I 3 883.3	60	80
I 3 573.6	60	15	I 3 738.7	35	25	I 3 883.7	30	20
I 3 574.0	50	15	I 3 788.9	60	10	I 3 885.2	40	50
I 3 578.7*LB$_1$C	500R	400R	I 3 789.7	50	10	I 3 886.8	125	125
3 582.6	35	12	I 3 790.2	30	10	I 3 891.9	40	25
I 3 593.5†C	500R	400R	I 3 790.5	50	15	I 3 894.0	60	40
3 599.4	30	20	I 3 791.4	80	40	I 3 897.7	40	25
I 3 601.7	50	30	I 3 792.1	60	40	3 902.1	40	30
I 3 603.7	15	50	I 3 793.3	50	30	I 3 902.9	100	100
I 3 605.3‡LC	500R	400R	I 3 793.9	50	30	I 3 903.2	35	30
3 609.5	20	12	I 3 794.6	50	30	3 907.8	30	10
3 610.1	20	8	I 3 797.1	50	30	I 3 908.8	200	150
3 612.6	35	25	I 3 797.7	100	20	3 912.0	40	....
3 615.6	30	10	3 801.2	35	3	I 3 915.8	125	80
3 619.5	30	8	I 3 804.8	100	30	I 3 916.2	100	60
3 626.3	20	3	3 806.8	35	35	I 3 917.0	30	8
II 3 631.7	10	35	I 3 807.9	25	12	I 3 917.6	20	12
3 632.8	80	35	3 812.3	40	15	I 3 919.2	300R	125
3 635.0	25	12	3 814.6	35	30	I 3 921.0	150	40
I 3 635.3	25	8	3 815.4	35	12	3 926.6	35	25
I 3 636.6	60	30	I 3 816.2	30	10	I 3 928.6	150	40
I 3 639.8	60	25	I 3 817.8	30	20	3 939.7	35	....
I 3 640.4	30	5	I 3 818.5	50	20	3 938.3	40	3
I 3 641.5	30	25	I 3 819.6	60	40	3 941.2	15	8
I 3 641.8	40	15	I 3 823.5	40	30	I 3 941.5	200R	60
I 3 649.0	40	20	I 3 825.4	40	15	3 945.5	50	15
I 3 653.9	100	25	I 3 826.4	40	20	3 946.0	50	7
I 3 656.3	80	25	I 3 830.0	150	50	3 948.9	25	2
II 3 662.8	25	8	I 3 831.0	40	25	I 3 951.1	50	8
I 3 663.2	35	20	I 3 834.7	25	12	I 3 951.8	40	5
3 666.0	20	15	I 3 836.1	25	8	I 3 952.4	60	18
I 3 666.6	20	15	I 3 841.3	150	80	I 3 953.2	60	12
3 676.3	40	15	I 3 849.0	80	50	3 960.8	40	8
II 3 677.9	3	70	I 3 839.4	40	30	I 3 963.7	300	300

For explanation of control and interfering line symbols see page 445

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

CHROMIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 3 969.1	80	50	4 077.1	35	10	4 190.1	40	15
I 3 969.7	200	90	4 077.7	30	10	I 4 191.3	70	15
I 3 971.3	80	50	4 081.7	25	2	I 4 191.8	50	6
I 3 972.7	60	12	4 085.0	15	1	4 192.1	40	15
I 3 976.7	300	300	4 090.3	30	15	4 193.7	100	25
I 3 978.7	80	40	4 092.2	25	2	4 195.0	70	25
I 3 979.8	80	20	I 4 097.7	20	....	4 197.2	70	25
I 3 981.2	100	50	I 4 098.0	20	....	4 198.5	100	30
3 983.2	20	6	I 4 098.2	20	....	4 200.1	80	8
I 3 983.9	200	60	4 099.0	30	8	I 4 203.6	100	20
I 3 994.3	80	60	4 101.2	30	2	I 4 204.2	50	6
3 990.0	80	40	4 104.9	35	8	4 204.5	80	30
I 3 991.1	200	60	I 4 108.4	30	4	4 206.9	80	25
I 3 991.7	100	50	I 4 109.6	40	10	4 208.4	100	25
3 992.1	20	1	I 4 110.9	20	....	4 209.4	100	40
I 3 992.8	50	70	I 4 111.4	20	....	4 209.8	80	20
I 3 994.0	60	20	I 4 111.7	20	....	4 211.3	100	30
3 998.9	25	2	I 4 120.6	40	10	I 4 212.7	80	8
3 999.7	40	10	4 121.3	35	8	4 213.2	60	8
4 001.4	200	80	4 121.8	40	10	I 4 206.4	60	25
4 003.9	30	12	I 4 122.3	30	5	I 4 217.6	150	70
4 012.5	70	60	4 123.4	35	15	4 221.6	80	35
4 014.7	40	8	I 4 126.5	100	50	I 4 222.7	100	15
I 4 018.2	35	8	4 126.9	30	4	4 224.5	60	12
4 022.3	80	40	I 4 126.3	20	10	4 226.8	125	30
4 023.7	40	15	I 4 127.6	30	10	I 4 230.5	70	8
I 4 024.6	20	1	4 131.4	30	20	4 232.2	70	5
4 025.0	100	25	4 134.4	25	3	I 4 232.9	60	....
4 026.2	100	35	4 142.2	35	8	4 234.5	60	2
4 027.1	80	30	4 146.2	20	2	I 4 237.7	70	....
4 028.0	35	....	II 4 146.5	20	1	I 4 239.0	100	15
4 030.7	40	30	4 146.7	25	2	4 240.7	200	30
4 031.1	30	6	4 152.8	50	12	I 4 242.4	4	50
I 4 033.3	30	8	I 4 153.1	40	6	I 4 248.3	30	2
I 4 034.0	30	....	I 4 153.8	50	30	4 248.7	35	2
I 4 035.3	80	12	4 161.4	50	30	I 4 252.2	35	10
4 039.1	100	40	4 163.6	100	50	I 4 254.3P§LB_2C	5000R	1000R
I 4 041.8	20	....	4 165.5	80	35	4 255.5	30	30
I 4 042.2	30	1	4 169.8	80	25	I 4 257.4	35	....
4 043.7	30	2	4 170.2	70	15	I 4 259.2	35	1
I 4 046.8	30	3	4 171.7	70	8	I 4 261.4	125	50
4 048.8	80	50	4 172.8	35	15	4 261.6	35	8
4 049.8	30	6	I 4 174.8	100	40	4 262.1	40	8
I 4 050.0	30	1	4 175.2	30	8	4 262.4	30	2
4 051.3	35	8	4 175.9	40	10	4 263.1	125	80
4 056.1	30	8	4 177.9	40	1	4 266.8	30	1
4 058.8	80	50	4 179.3	100	40	4 268.8	30	3
4 065.7	80	35	4 180.0	25	1	4 270.0	40	6
4 066.9	25	30	4 184.9	35	10	4 271.1	30	12
4 074.9	25	10	4 185.3	30	3	I 4 272.9	40	30
4 076.1	30	15	4 186.4	50	10	I 4 274.8p‖LB_3C	4000R	800R

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

CHROMIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
4 276.0	30	15	I 4 412.3	35	10	4 571.7	50	40
4 277.8	25	....	4 413.9	25	15	4 575.1	25	5
4 280.4	80	50	I 4 414.4	15	....	4 578.3	25	2
I 4 284.7	40	8	I 4 424.3	25	35	I 4 580.1	300	125
I 4 289.7p¶LB$_4$C	3000R	800R	I 4 428.5	25	6	4 584.1	20	1
4 292.0	35	20	4 432.2	30	15	4 586.1	25	6
I 4 293.6	50	8	I 4 458.5	50	125	I 4 587.9	30	....
I 4 295.8	125	40	I 4 459.7	25	25	II 4 588.2	10	600
I 4 297.1	100	15	I 4 460.8	25	....	II 4 591.4	200	125
4 297.7	125	30	I 4 465.4	20	10	4 592.5	25	1
I 4 299.7	100	50	I 4 467.6	20	2	4 595.6	50	60
4 300.5	100	20	I 4 473.8	25	1	4 598.4	20	4
4 301.2	100	25	I 4 475.3	40	6	4 600.1	20	50
4 302.8	40	2	I 4 477.1	20	....	I 4 600.8	150	150
I 4 305.5	150	20	4 482.9	25	12	4 605.8	30	....
4 307.5	35	1	4 488.1	25	15	I 4 613.4	150	60
4 312.5	30	1	4 489.5	25	15	I 4 616.1	300R	200
I 4 319.6	100	20	I 4 491.7	25	1	II 4 618.8	6	80
I 4 320.6	125	6	4 491.9	50	4	4 619.6	50	30
4 321.2	70	2	4 492.3	30	15	4 621.9	20	....
4 321.6	70	3	I 4 496.9	200	200	4 622.0	50	40
4 325.1	125	130	4 498.7	30	15	4 622.5	30	30
4 332.6	125	2	4 500.3	50	30	4 622.8	20	10
I 4 337.6	500	300	4 501.1	40	30	I 4 626.2	100	125
4 338.4	35	4	4 506.9	30	30	4 632.2	25	8
4 338.8	50	8	4 511.9	80	100	I 4 633.3	20	6
I 4 339.5	300R	300	I 4 514.5	30	8	II 4 634.1	5	80
I 4 339.7	150	150	4 515.4	25	10	4 637.2	20	8
I 4 340.1	80	30	4 521.1	25	10	4 637.8	20	6
I 4 343.2	60	12	4 524.8	20	3	I 4 646.2	100	150
I 4 344.5	400R	300	4 526.1	20	6	I 4 646.8	35	3
4 345.1	30	3	I 4 526.5	50	30	4 648.1	40	6
4 346.8	200	40	I 4 530.7	150	125	4 648.9	50	3
4 347.5	30	1	I 4 535.1	50	30	4 649.5	60	3
I 4 351.1	100	150	I 4 535.7	125	100	I 4 651.3	100	100
I 4 351.8	300	300	I 4 539.8	40	25	I 4 652.2	200R	150
4 354.0	20	3	4 540.7	40	40	I 4 654.7	70	8
I 4 359.6	200	150	I 4 541.1	30	8	4 656.2	50	4
4 363.1	25	35	4 541.5	30	6	I 4 663.3	40	25
I 4 371.3	200	150	4 542.6	30	8	I 4 663.8	50	15
I 4 373.3	50	50	4 543.7	20	2	I 4 664.8	70	20
4 374.2	50	60	I 4 544.6	100	70	4 665.9	20	10
4 375.3	25	30	I 4 545.3	25	12	4 666.2	35	8
4 376.8	20	20	I 4 546.0	200	125	I 4 666.5	50	25
4 377.5	25	10	4 553.9	20	3	I 4 669.3	50	20
I 4 381.1	30	25	4 554.8	25	2	I 4 680.5	50	25
I 4 385.0	150	200	4 555.1	15	50	4 680.9	60	8
I 4 391.8	50	35	4 556.2	40	12	4 684.6	20	....
I 4 397.3	25	5	II 4 558.7	20	600	4 686.2	20	1
I 4 399.8	20	3	I 4 565.5	20	30	I 4 689.4	80	35
I 4 410.3	25	8	4 569.6	50	10	4 693.9	50	20

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

CHROMIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
4 695.2	50	4	4 870.8	150	25	I 5 287.2	40	....
I 4 697.1	50	12	4 874.7	20	....	I 5 298.3	15R	25
I 4 698.5	60	12	4 880.0	25	....	I 5 300.7	25	4
I 4 698.6	40	8	I 4 884.9	25	....	I 5 304.2	20	....
4 699.6	30	1	I 4 885.8	60	....	I 5 312.9	40	....
I 4 700.6	50	4	4 887.0	125	30	I 5 318.8	30	....
4 706.1	30	1	I 4 888.5	100	....	I 5 345.8	300R	25
I 4 708.0	200	150	4 894.4	30	....	I 5 348.3	150R	15
4 717.7	20	1	I 4 903.2	125	....	5 387.0	20	....
I 4 718.4	200	150	4 905.1	30	....	5 400.6	30	1
4 723.1	125	8	4 920.9	50	....	I 5 409.8	300R	30
4 724.4	125	10	4 922.3	200	40	5 480.5	20	....
4 727.2	80	20	4 930.2	35	....	I 5 628.6	25	2
4 729.7	30	6	4 936.3	200	5	I 5 694.7	35	....
4 730.7	100	50	I 4 942.5	125	3	I 5 698.3	30	2
4 737.4	200	80	4 944.6	35	....	5 702.3	20	....
4 743.1	40	....	4 954.8	100	8	5 781.8	20	....
I 4 745.3	80	2	4 986.0	25	....	5 783.1	30	....
4 752.1	100	40	I 5 013.3	60	2	5 783.9	30	....
4 754.7	80	....	I 5 021.9	20	....	5 785.0	20	....
I 4 755.1	70	....	I 5 048.8	30	....	5 788.0	50	....
4 756.1	300	100	I 5 051.9	50	....	I 5 791.0	40	....
4 757.3	25	....	I 5 065.9	30	....	5 838.6	200	100
4 761.2	25	....	I 5 067.7	50	....	5 888.0	20	....
4 764.3	200	35	5 068.3	20	....	I 6 330.1	200	8
I 4 764.6	35	....	I 5 072.9	35	....	I 6 362.9	150	8
I 4 766.6	80	6	I 5 091.9	25	....	6 421.4	35	....
4 767.9	100	8	I 5 110.8	40	....	6 501.2	35	....
I 4 770.7	35	....	I 5 113.1	25	....	6 529.2	40	....
I 4 774.6	20	....	I 5 122.1	20	....	I 6 538.0	35	....
4 775.1	35	....	5 139.7	50	1	I 6 572.9	25	....
4 783.1	25	....	I 5 144.7	30	....	I 6 580.9	30	....
I 4 789.4	300	100	5 166.2	80	2	6 594.7	60	....
I 4 790.3	100	1	I 5 177.4	50	....	6 608.9	25	....
4 792.5	200	40	I 5 184.6	60	1	I 6 630.0	50	....
4 796.2	125	1	I 5 192.0	50	....	I 6 661.1	100	....
4 797.7	25	....	I 5 196.4	50	3	I 6 669.3	80	....
4 801.0	200	70	I 5 200.2	30	....	6 762.4	50	....
I 4 804.7	35	....	I 5 204.5$_p$	400R	100	6 789.2	40	....
I 4 806.3	80	....	I 5 206.0$_p$	500R	200	I 6 881.6	15	....
4 810.7	30	....	I 5 208.4	500R	100	I 6 882.4	20	....
4 814.3	100	....	5 221.8	25	....	I 6 883.0	70	....
4 816.1	40	....	I 5 239.0	60	....	I 6 924.1	60	....
4 823.9	25	....	I 5 240.5	20	....	I 6 925.2	50	....
I 4 829.4	200	40	I 5 243.4	50	....	I 6 978.5	125	....
4 831.6	25	....	I 5 247.6	50	15	I 6 979.8	20	....
I 4 836.9	80	....	I 5 255.1	20	3	7 207.9	15	....
I 4 855.1	20	....	I 5 264.2	100R	20	I 7 355.9	80	....
I 4 857.3	25	....	I 5 265.7	30	10	I 7 400.2	80	....
I 4 861.2	80	....	I 5 272.0	25	1	I 7 462.3	80	....
4 861.8	125	8						

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

CHROMIUM (*Continued*)

Control lines:		Interfering lines:	Control lines		Interfering lines:
*Co	3659.4	*Ba Co Hg Mn Mo	Fe	4307.9	
Fe	3719.9		Ti	4337.9	
Mo	3624.5		¶Ca	4283.1	¶Ba Be Ca Co Cs Fe
†Co	3518.4	†Ba Bi Cu Sb	Mo	4232.6	Ni Pb Pt Ti V
Ni	3610.5		Ti	4298.7	
‡Co	3594.9	‡Co Fe Mn V	B_1Ni	3619.4	**Fe W Ag Ta Ce Th
Fe	3618.8		B_2Fe	4245	
§Fe	4260.5	§Be Bi Co Cu Fe Mo Cb Ce U Zr	B_3Fe	4247	
‖Cu	4651.2	‖Co Cu Fe Li Mo Pt u Ti Ce Cb	B_4Fe	4352	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

COBALT

Co

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 011.5	15	50	I 2 424.9	250R	....	I 2 585.3	50	....
2 014.6	20	....	I 2 429.2	25	3	II 2 587.2	10	100
II 2 022.3	18	75	I 2 432.2	40R	....	I 2 590.6	75	....
II 2 027.0	15	50	2 432.5	....	80	2 605.7	30	200
2 097.5	20	....	2 432.1	20	2	I 2 606.1	40	....
2 104.7	25	2	2 436.7	50R	25	I 2 610.8	40	1
2 106.8	25	2	I 2 439.0	20R	20	2 613.5	25	....
I 2 164.6	30R	12	2 447.8	4	100R	I 2 614.1	30	....
2 179.0	25	....	2 450.0	40	200	II 2 614.4	6	60
II 2 181.7	80	8	I 2 456.2	20	7	I 2 616.3	40	2
2 199.7	20	....	2 460.2	20	....	I 2 617.9	50	....
2 200.7	80	....	I 2 460.8	20	3	I 2 619.3	50	4
2 276.5	20R	5	2 462.1	20	1	I 2 622.4	30R	15
I 2 284.8	30	....	II 2 464.2	40	150	I 2 623.8	40	3
II 2 286.2P	40	300	2 467.1	2	80	I 2 627.6	50	....
II 2 307.9p	25	50	I 2 467.7	20	3	I 2 630.0	30	1
II 2 311.6	15	50	I 2 476.6	40	25	II 2 632.2	10	49
II 2 314.1	25	35	II 2 485.4	25	75	I 2 648.6	5	40
II 2 315.0	25	30	2 490.4	5	80	I 2 649.9	50	5
II 2 324.3	20	50	2 493.9	30	9	I 2 650.3	50	25
I 2 325.6	50	....	2 498.8	2	80	II 2 663.5	15	60
II 2 326.5	20	30	II 2 506.5	50	200	II 2 669.9	....	100
I 2 358.2	20	30	I 2 507.7	40	8	I 2 673.5	25	....
II 2 363.8	25	50	I 2 511.0	10R	20	2 679.8	75	....
2 373.4	20	2	II 2 519.8	40	200	2 680.1	25	3
II 2 378.6p	25	50	2 521.4	75R	150	I 2 685.3	75	....
I 2 380.5	20	10	II 2 525.0	50	700	I 2 694.4	25	....
II 2 388.9pF	10	35	II 2 528.6	4	200	II 2 694.7	25	200
II 2 396.8	90	....	I 2 529.0L	50R	....	I 2 695.8	50	....
II 2 397.4	4	25	I 2 530.1	40	300	II 2 697.0	....	60
I 2 400.6	30	....	I 2 532.2	....	75	I 2 705.8	15	100
I 2 400.8	30	2	2 533.8	5R	60	II 2 706.7	....	100
2 401.1	30	2	II 2 541.9	40	300	II 2 707.5	....	100
2 401.6	30	2	I 2 544.3	50R	100	2 708.8	30	20
I 2 402.2	30R	....	I 2 548.3	20	75	II 2 714.4	12	200
II 2 404.2	30	50	I 2 553.0	40R	....	I 2 716.0	75	75
I 2 406.3	25	1	I 2 556.8	50	150	2 719.6	25	....
I 2 407.3	100	2	II 2 559.4	10	60	I 2 722.1	50	....
II 2 408.8	25	25	2 561.3	25	12	2 731.1	50	15
I 2 409.1	20	....	II 2 564.0	15	100	I 2 740.5	50	4
2 410.5	40	....	I 2 567.3	50R	....	I 2 745.1	50	60
I 2 411.6	250R	50	I 2 572.2	50	12	I 2 746.0	50	....
I 2 414.5	40R	15	2 573.4	40	12	I 2 752.1	40	1
I 2 405.3	40R	18	2 573.5	30R	12	I 2 758.5	30	....
2 407.3	25	....	2 576.1	30	....	I 2 761.4	75	5
II 2 407.7	20	20	I 2 578.9	30	....	I 2 764.2	100R	....
2 419.1	20	1	II 2 580.3L	15	100	2 766.2	50	45
2 420.7	8	80	I 2 550.8	50	4	I 2 766.4	50	3
2 422.6	30	3	II 2 582.2	50	500	2 768.7	20	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

COBALT (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 772.7	30	....	I 2 943.5	30	....	I 3 107.0	70	3
I 2 775.0	50	....	2 954.7	2	100	I 3 107.5	15	3
II 2 775.2	30	100	2 955.4	30	....	I 3 109.5	60	1
I 2 775.6	50	....	2 957.7	50	1	I 3 110.0	60	2
I 2 779.8	75	8	2 966.9	30	....	I 3 110.8	60	2
I 2 785.9	50	....	I 2 978.0	30	....	I 3 111.3	20	3
2 790.3	30	....	I 2 987.2	75R	50	I 3 113.5	100	4
I 2 791.0	50	....	I 2 989.6	75R	30	I 3 118.2	60	2
I 2 792.4	40	3	I 2 995.2	50	1	I 3 121.4C	150R	6
2 794.8	100R	15	I 3 000.5	80	1	I 3 121.6	60R	3
I 2 796.2	50	5	I 3 005.8	100	2	I 3 126.5	20	....
I 2 797.1	50	2	I 3 013.6	60R	4	I 3 126.7	70	....
2 802.7	100	200	I 3 015.7	60	2	I 3 127.3	100	....
I 2 803.8	100	12	I 3 017.3	60	....	I 3 129.0	25	....
II 2 810.9	5	75	I 3 017.5	100R	5	I 3 129.5	40	2
I 2 811.1	50	....	3 020.6	60	....	I 3 132.2	40	....
I 2 811.5	50	....	I 3 022.4	60	2	I 3 136.7	60	....
I 2 815.0	25	....	I 3 026.4	100	40	I 3 137.3	150R	....
I 2 815.6	50R	....	I 3 034.4	80	2	I 3 137.5	50	....
I 2 808.6	30	....	I 3 038.3	25	....	I 3 137.8	60	2
I 2 820.0	50	....	I 3 039.6	70	....	I 3 139.9	150R	10
II 2 821.7	30	10	I 3 042.5	80R	8	I 3 140.7	20	3
I 2 825.2	75	....	3 044.0C	400R	....	I 3 145.0	30	....
II 2 825.2	5	200	I 3 048.1	25	....	I 3 147.1	150R	....
I 2 833.9	40	....	I 3 048.9	150R	....	I 3 149.3	60	....
I 2 834.4	50	....	I 3 050.5	60	....	I 3 152.7	100	....
II 2 834.9	2	75	I 3 050.9	60	....	3 154.7	100	....
I 2 837.2	75R	....	I 3 054.7	60	....	I 3 154.8	100	4
I 2 842.4	30	....	I 3 062.2C	60	1	I 3 158.8	150R	....
II 2 845.6	....	50	I 3 064.4	100	....	I 3 159.7	100	2
II 2 848.4	....	60	3 072.0C	80	2	I 3 161.7	60	....
I 2 850.0	75	....	I 3 072.3C	200R	100	I 3 168.1	100	....
I 2 851.0	30	....	I 3 072.7C	20	....	3 169.8	100	....
I 2 859.7	40	....	I 3 073.5	60	2	I 3 174.1	20	....
I 2 862.6	50	....	I 3 079.4	80	2	I 3 174.9	80	....
II 2 870.0	....	50	3 082.6	150R	50	3 177.3	100	....
2 871.2	....	100	I 3 082.8	35	....	I 3 182.1	80	2
2 879.6	25	....	I 3 086.4	80	2	I 3 186.0	40	....
II 2 880.3	....	50	I 3 086.8	200R	....	I 3 186.3	70	....
I 2 882.2	30	....	I 3 087.8C	60	....	I 3 188.4	100	2
I 2 886.4	50	2	I 3 089.6	100R	....	I 3 189.8	60	3
2 892.2	25	....	I 3 090.3	80	1	I 3 191.3	35	....
I 2 895.5	20	....	I 3 095.7	60	2	I 3 192.2	35	....
I 2 899.8	25	1	I 3 096.4	60	3	I 3 193.2	50	....
2 903.2	25	1	I 3 096.7	60	3	I 3 198.7	60	2
I 2 919.6	30	....	I 3 098.2	100R	5	I 3 199.3	35	....
I 2 927.7	50	1	I 3 099.7	50	....	I 3 203.0	40	....
I 2 928.8	50	1	I 3 102.4	60	4	I 3 210.2	80	2
I 2 929.5	75	....	I 3 103.7	80	2	I 3 219.2	60	....
II 2 930.4	....	150	I 3 104.0	60R	....	I 3 224.6	60	....
II 2 943.2	....	100	I 3 105.9	30	....	3 227.0	80R	....

For explanation of control and interfering line symbols see page 445

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

COBALT (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 3 232 9	60	25	I 3 348.1	80	....	I 3 438.9	30	....
I 3 235.5	60	....	I 3 351.5	35	2	I 3 442.9	400R	15
I 3 237.0	100	....	3 354.2	30	....	3 443.2	25	2
I 3 243.8	100	....	I 3 354.4	200R	....	I 3 443.6C	500R	100
I 3 247.0	35	....	I 3 356.5	150	2	I 3 446.1	60	....
I 3 247 2	80	....	I 3 356.8	25	....	II 3 446.4	3	60
I 3 250.0	60	....	I 3 359.1	35	....	I 3 449.2C	500R	125
I 3 254.2	300R	....	I 3 359.3	100	2	I 3 449.4C	500R	125
I 3 258.0	60	....	I 3 361.6	80	2	I 3 453.5P‡	3000R	200
I 3 260.8	70	4	I 3 352.8	80	....	LB$_1$CA		
I 3 263.2	30	....	I 3 363.3	30	2	I 3 455.2	2000R	10
I 3 264.8	35	2	I 3 363.8	80R	....	I 3 456.9	30	2
I 3 265.4	35	2	I 3 364.3	30	2	I 3 458.0	60	....
I 3 271.8	60	....	I 3 367.1	300R	30	I 3 461.2	100	3
I 3 276.5	35	2	I 3 370.3	80	2	I 3 462.8	1000R	80
I 3 277.3	60	....	II 3 370.9	....	50	I 3 465.8p	2000R	25
I 3 278.8	70	2	I 3 373.2	60	....	I 3 469.0	20	....
I 3 279.3	60	2	I 3 374.0	60	....	I 3 471.4	80	25
I 3 283.5	80	....	I 3 374.3	60	....	I 3 474.0	3000R	100
I 3 283.8	60	....	I 3 377.1	100	....	I 3 474.5	30	2
I 3 287.2	60	....	I 3 378.4	30	2	I 3 476.4	100R	....
I 3 293.9	40R	....	3 378.7	40	2	I 3 478.6	40	2
I 3 298.7	70	2	I 3 381.5	100	....	I 3 468.7	60	2
I 3 303.9	60R	....	I 3 383.9	60	....	I 3 470.0	80	2
I 3 305.7	20	....	I 3 385.2	250R	15	I 3 483.4	300R	10
I 3 307.2	80	....	I 3 388.2	250R	12	3 485.4	100	3
I 3 308.5	30	....	I 3 390.4	30	2	I 3 487.7	20	1
I 3 308.8	40	....	I 3 395.4	400R	50	I 3 489.4	100R	25
I 3 312.1	60	2	3 398.8	20	....	I 3 490.7	60	....
I 3 312.8	20	....	I 3 401.9	20	....	I 3 491.3	200R	8
I 3 314.1	100	....	I 3 405.1*C	2000R	150	I 3 495.7	1000R	25
I 3 318.4	35	....	3 405.8C	30R	....	I 3 496.7	150R	4
I 3 319.2	60	....	I 3 409.2	1000R	125	I 3 496.8	30	....
3 319.5	80	....	I 3 412.3†C	1000R	100	II 3 501.7	5	100
I 3 319.8	35	2	I 3 412.6C	1000R	40	I 3 502.3§C	2000R	20
I 3 321 9	25	....	I 3 414.7	200	....	I 3 502.6C	60	5
I 3 322.2	100	....	I 3 415.5	20	....	I 3 506.3	400R	15
I 3 325.2	80	3	II 3 415.8	100R	20	I 3 509.8	40R	40
I 3 326.6	60	....	I 3 417.2	400R	....	I 3 512.6	400R	100
3 327.0	100	....	I 3 417.7	25	....	I 3 513.5	300R	25
I 3 328.2	40	....	I 3 417.8	30	2	I 3 518.3	200	100
I 3 329 0	20	....	I 3 420.8	80	2	I 3 520.1	100	....
I 3 329.5	80	....	I 3 421.6	20	2	I 3 521.6	200R	25
I 3 333.4	100	....	I 3 424.5	80	2	I 3 523.4	300R	25
I 3 334.1	250R	....	3 428.2	100	2	I 3 526.8	300R	25
I 3 337.2	60	2	3 429.7	30	....	I 3 529.0	200R	....
I 3 339.8	150	....	I 3 431.6	500R	40	I 3 529.8p	1000R	30
3 341.3	60	2	I 3 432.3	60	....	I 3 533.4	200	....
I 3 341 9	25	....	I 3 433.0	1000R	150	I 3 543.3	35	....
I 3 342.7	150	....	I 3 437.7	150	....	I 3 550.6	200	....
I 3 346.9	100	2	I 3 438.7	80	....	I 3 552.7	20	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

COBALT (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 3 553.0	20	....	I 3 732.4	200R	....	I 3 933.7	80	....
I 3 558.8	40	....	I 3 733.5	150	....	I 3 933.9	60	....
I 3 560.9	200	25	I 3 734.1	70	....	I 3 936.0	400R	15
I 3 565.0	150	....	I 3 734.9	60	....	I 3 940.9	100	....
I 3 569.4	400R	100	I 3 735.9	200R	....	I 3 941.7	200	....
I 3 575.0	200	25	I 3 740.2	60	....	I 3 945.3	200	15
I 3 575.4	200R	25	I 3 745.5	300R	....	I 3 947.1	20	2
I 3 584.8	25	....	I 3 729.9	60	5	I 3 952.3	40	4
I 3 585.2	60	....	I 3 751.6	100	60	I 3 952.9	100	75
I 3 587.2	200R	50	I 3 754.3	30	3	I 3 957.9	100R	....
I 3 594.9	200	....	I 3 755.4	100	....	I 3 961.0	60	10
I 3 602.1	200	35	I 3 759.7	30	....	I 3 969.1	100	6
I 3 605.4	60	....	I 3 760.4	30	....	I 3 972.6	100	6
I 3 611.7	25	....	I 3 774.6	200	....	I 3 973.1	150	6
II 3 621.2	15	50	I 3 777.5	200	....	I 3 974.7	100	10
I 3 625.0	20	....	I 3 805.8	20	....	I 3 975.3	30	5
I 3 627.8	200	....	I 3 808.1	200	7	I 3 977.2	20	....
I 3 631.4	50	25	I 3 811.1	30	....	I 3 978.7	100	....
I 3 631.9	20	....	I 3 812.5	100	....	I 3 978.9	20	2
3 632.8	60	....	I 3 813.9	30R	....	I 3 979.5	150	12
3 634.7	70	10	I 3 814.5	35	....	I 3 987.1	80	....
I 3 636.7	40	6	I 3 816.3	60	50R	I 3 990.3	80	10
I 3 637.3	30	5	I 3 816.5	60	....	I 3 991.5	30	....
I 3 639.4	200	20	I 3 816.9	70	5	I 3 991.7	60	6
I 3 641.8	60	8	I 3 817.9	18	4	I 3 994.5	60	....
I 3 643.2	80	15	I 3 819.9	20	3	I 3 995.3‖C	1000R	20
I 3 645.2	60	3	I 3 841.5	60	....	I 3 997.9	200	20
I 3 647.1	30	4	I 3 842.1	400R	20	I 4 013.9	300	....
I 3 647.7	100	8	I 3 843.7	60	....	I 4 019.3	80	....
3 648.1	20	2	I 3 845.5	500R	100	I 4 020.9	500	....
3 649.4	200	4	I 3 851.0	100	....	I 4 023.4	200	....
I 3 651.3	20	....	3 856.8	80	2	I 4 027.0	200	4
I 3 652.5	200R	....	I 3 861.2	300R	15	I 4 035.6	150	3
I 3 654.4	35	....	I 3 863.6	30	....	I 4 045.4	400	....
I 3 657.0	60	6	I 3 870.5	70	8	I 4 052.9	40	....
I 3 662.3	100	25	I 3 873.1	500R	80	I 4 057.0	20	2
I 3 670.1	20	....	I 3 874.0	400R	80	I 4 057.2	100	....
3 676.6	100	35	I 3 876.8	300	40	I 4 058.2	100	....
I 3 683.1	200R	....	I 3 878.7	70R	....	I 4 058.6	100	....
I 3 684.5	200	....	I 3 881.9	300R	30	I 4 068.5	150	100
I 3 690.7	60	10	I 3 884.6	100	....	I 4 076.1	70	....
I 3 693.1	80	15	I 3 891.1	20	....	I 4 077.4	100	2
I 3 683.5	35	10	I 3 894.1C	1000R	100	I 4 082.6	50	....
3 702.2	200	....	I 3 895.0	300R	3	I 4 086.3	400	15
I 3 704.1	300R	35	I 3 898.5	80R	6	I 4 088.3	50	....
I 3 707.5	30	....	I 3 906.3	150	....	I 4 090.4	20	....
I 3 708.8	100	....	I 3 909.9	200	....	I 4 092.4	600	15
I 3 711.7	35	....	I 3 917.1	80	10	I 4 092.8	25	10
I 3 712.2	40	8	I 3 920.1	20	....	I 4 104.4	30	2
I 3 726.7	30	....	I 3 920.7	25	....	I 4 104.8	50	....
I 3 730.5	200R	....	I 3 922.8	100	....	I 4 110.5	600	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

COBALT (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 4 118.8¶	1000R	....	I 4 580.1	300	3	I 4 966.6	100	....
I 4 121.3**	1000R	25	I 4 581.6	1000	10	I 4 972 0	150	....
4 158.4	25	3	I 4 588.7	100	1	I 4 979 9	60	....
I 4 187.3	50	3	I 4 594.6	400	....	I 4 988.0	500R	....
I 4 234.0	100	....	I 4 596.9	400	....	I 5 094.9	100	....
I 4 252.3	150	....	I 4 614.0	60	....	I 5 108.9	200	....
I 4 285 8	125	....	I 4 620.8	25	....	I 5 113.2	100	....
I 4 339.6	50	....	I 4 622.7	30	....	I 5 122.8	150	....
I 4 371 1	25	....	I 4 623.0	150	....	I 5 124.8	25	....
I 4 445.7	125	2	I 4 625.8	200	....	I 5 125.7	100	....
I 4 466 9	300	5	I 4 628.9	125	....	I 5 126.2	200	....
I 4 469 6	300	5	I 4 629.4	600	5	I 5 133.4	50	....
I 4 471 6	100	4	I 4 644.3	70	....	I 5 145.5	80	....
I 4 121.3	1000R	25	I 4 654.8	25	....	I 5 146.7	400	....
4 158.4	25	5	I 4 657.4	100	35	I 5 149.8	100	....
I 4 187.3	50	3	I 4 663.4	700	....	I 5 154.1	200	....
I 4 234 0	100	....	I 4 682.4	500	....	I 5 156.3	300	....
I 4 252.3	150	....	I 4 685.9	30	....	I 5 158.4	40	....
I 4 285.8	125	....	I 4 693.2	500	25	I 5 158.8	40	....
I 4 339.6	50	....	I 4 698.4	300	8	I 5 165.2	30	....
I 4 371.1	25	....	I 4 699.2	25	....	I 5 176.1	500R	....
I 4 445.7	125	2	I 4 718.5	50	....	5 183.6	35	....
I 4 466.9	300	5	4 721.4	8	100	I 5 192.4	100	....
I 4 469.6	300	5	I 4 727.9	300	....	5 210.1	100	....
I 4 471.6	100	4	I 4 734.8	150	....	I 5 210.8	50	....
I 4 477.2	30	....	4 737.8	150	1	I 5 211.8	100	....
I 4 478.3	100	3	I 4 746.1	100	....	I 5 212.7	300	....
I 4 483.6	20	....	I 4 749.7	500	100	I 5 222.5	50	....
I 4 483.9	100	....	I 4 754.4	200	2	I 5 230.2	300R	....
I 4 484.5	60	....	I 4 756.7	100	....	5 235.2	100	....
I 4 486.7	50	1	I 4 767.1	100	....	I 5 247.9	500	....
I 4 494.8	100	....	I 4 768.1	300	10	I 5 250.0	200	....
I 4 514.2	60	2	I 4 771.1	500	....	I 5 254.7	200	....
I 4 517.1	300	6	I 4 776.3	300	....	I 5 257.6	400	....
I 4 519.3	40	....	I 4 778.3	100	....	I 5 265.7	30	10
I 4 527.9	100	2	I 4 780.0	500	500	I 5 265.8	25	....
I 4 531 0	1000	8	I 4 781.4	400	2	I 5 266.3	100	....
I 4 534.0	500	8	I 4 785.1	50	....	I 5 266.5	500	....
I 4 540 8	30	....	I 4 792.9	600	5	I 5 268.5	500	....
I 4 543.8	500	....	I 4 795.9	100	....	I 5 276.2	400	....
I 4 545.2	50	....	I 4 796.4	100	....	I 5 280.6	500	....
I 4 549.7	600	....	I 4 813.5	1000	6	I 5 283.5	125	....
4 552.4	25	....	I 4 814.0	100	2	I 5 301.1	700	....
I 4 553.3	25	....	I 4 840.3	700	150	I 5 310.2	20	....
I 4 561.9	25	....	I 4 843.5	300	....	I 5 312.7	400	....
4 564 2	35	1	I 4 867.9	800	100	I 5 316.8	300	....
I 4 565 6	800	12	I 4 899 5	400	....	I 5 325.3	300	....
I 4 566 6	100	2	I 4 904 2	80	....	I 5 326.0	25	....
I 4 570 0	300	....	I 4 928 3	200	....	I 5 331 5	500	80
I 4 574 9	20	....	I 4 934 0	40	....	I 5 332.7	200	....
I 4 579.4	25	....	I 4 953.2	50	....	I 5 333.7	100	....

For explanation of control and interfering line symbols see page 445

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

COBALT (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 5 334.8	70	....	6 016.6	40	....	I 6 635.1	25	....
I 5 336.2	50	....	6 021.8	50	....	I 6 678.8	125	....
I 5 338.5	100	....	I 6 049.1	50	....	6 684.1	30	....
I 5 341.3	300	....	I 6 070.7	20	....	I 6 684.9	30	....
I 5 342.7	800	....	I 6 082.4	300	....	I 6 756.6	25	....
I 5 343.4	600	....	I 6 086.6	80	....	I 6 758.1	25	....
I 5 347.5	80	....	I 6 093.1	200	....	6 767.6	35	....
I 5 349.1	80	....	I 6 107.9	25	....	6 771.1	200	....
I 5 352.1	500	....	I 6 117.0	80	....	I 6 784.9	25	....
I 5 353.5	500	....	6 122.2	40	....	I 6 789.3	15	....
I 5 358.9	40	....	I 6 122.7	125	....	I 6 808.9	25	....
I 5 359.2	300	....	I 6 129.1	20	....	I 6 814.9	150R	....
I 5 362.8	500	....	6 162.2	60	....	6 819.5	20	....
I 5 368.9	30	....	I 6 189.0	200	....	I 6 847.0	25	....
I 5 369.6	500	....	I 6 211.2	25	....	I 6 872.4	200	....
I 5 381.1	150	....	I 6 231.0	200	....	I 6 905.9	40	....
I 5 381.7	150	....	I 6 232.4	25	....	6 908.1	30	....
I 5 390.5	25	....	I 6 249.5	125	....	I 6 910.8	15	....
I 5 402.0	100	....	I 6 257.6	70	....	I 6 937.8	150	....
I 5 407.5	100	....	I 6 273.0	70	....	I 6 997.2	200	....
I 5 408.1	30	....	I 6 275.1	25	....	I 7 004.8	150	....
I 5 437.0	25	....	I 6 276.6	40	....	I 7 016.6	300	....
I 5 444.6	400	....	I 6 282.6	300	....	I 7 027.8	200	....
I 5 452.3	25	....	6 311.3	30	....	I 7 032.5	25	....
I 5 454.6	300	....	I 6 313.0	50	....	I 7 052.9	300	....
I 5 469.3	125	....	I 6 314.5	50	....	I 7 054.0	200	....
I 5 470.5	50	....	I 6 320.4	80	....	I 7 055.9	25	....
I 5 477.1	40	....	6 347.8	125	....	I 7 085.0	500	....
I 5 483.3	500	....	I 6 351.4	25	....	I 7 094.5	40	....
I 5 484.0	150	....	I 6 395.2	125	....	7 102.6	25	....
I 5 489.6	150	....	I 6 417.8	200R	....	I 7 113.6	150	....
I 5 523.2	300	....	I 6 421.7	20	....	7 122.3	50	....
I 5 525.0	25	....	I 6 429.9	50	....	I 7 124.5	50	....
I 5 530.8	500	....	I 6 430.3	30	....	I 7 134.3	200	....
I 5 545.9	25	....	6 439.2	80	....	I 7 154.7	200	....
I 5 590.7	500	....	I 6 444.7	25	....	I 7 159.2	250	....
5 594.5	40	....	I 6 450.2	1000	....	I 7 193.6	200	....
5 598.5	50	....	I 6 451.1	70	....	I 7 250.1	80	....
I 5 636.1	20	....	I 6 455.0	200	....	I 7 285.3	200	....
I 5 637.7	20	....	6 462.6	60	....	I 7 315.7	25	....
I 5 647.2	600	....	I 6 463.0	25	....	I 7 353.5	25	....
I 5 659.1	25	....	I 6 477.9	80	....	I 7 354.6	150	....
5 857.5	20	....	I 6 490.3	70	....	I 7 388.7	200	....
I 5 915.5	200	....	6 493.7	25	....	I 7 417.4	300	....
I 5 935.4	150	....	I 6 551.4	80	....	I 7 437.2	30	....
I 5 946.5	70	....	I 6 563.4	200	5	I 7 457.4	200	....
I 5 991.9	900R	....	I 6 595.9	150	....	I 7 533.5	40	....
I 6 000.7	80	....	I 6 617.1	30	....	I 7 554.0	200	....
I 6 006.4	50	....	I 6 617.5	30	....	I 7 565.0	20	....
I 6 007.7	50	....	6 623.8	70	....	I 7 586.7	20	....
I 6 013.6	30	....	I 6 632.4	150	....	I 7 590.6	35	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

COBALT (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 7 610.2	35	....	I 7 840.1	40	....	I 7 926.6	80	....
I 7 712.7	80	....	I 7 855.9	40	....	I 7 957.8	40	....
I 7 734.2	40	....	I 7 869.9	80	....	I 7 960.6	25	....
I 7 809.2	20	....	I 7 871.4	80	....	I 7 966.1	40	....
I 7 838.2	80	....	I 7 908.7	80	....	I 7 987.4	80	....

Control lines:	Interfering lines:
*Cd 3466.2	*Bi Cd Cr Cu Mo V Cb Ti Ag Ce Zr
Cr 3368.1	
Fe 3521.3	
†Cr 3368.1	†Bi Cr Cu Fe Mn
Ni 3524.5	
‡B 2496.8	‡Cr Mo Ni Pb Pt Rh Ti Ce Fe Th
Ni 3493.0	
Ni 3472.6	
AFe 3451.9	

Control lines:	Interfering lines:
§Ba 4166.0	§Ag Ba Cr Mo Ni
Fe 3558.5	
Ti 3394.6	
‖Ba 4166.0	‖Ba Cr Fe Mn Mo
¶Fe 4181.8	¶As Cr Ge Mn Mo
**Fe 4120.2	**As Bi Cr Cu Fe Mn Ni Ti V W
Bi 4722.2	
Mo 4081.5	
B$_1$Mn 3442.0	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

COLUMBIUM

Cb

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 029.3	10	50	2 715.9	2	100	2 932.1	....	50
2 109.4	15	50	2 716.6	10	200	2 932.7	1	80
2 126.5	15	50	2 722.0	10	200	2 941.5	50	300
2 242.6	5	50	2 723.7	2	200	2 945.9	2	100
2 265.6	....	50	2 730.3	2	200	2 950.9	15	200
2 274.1	12	300	2 733.3	30	50	2 972.6	40	100
2 274.2	2	80	2 733.7	2	50	2 974.1	5	200
2 276.2	....	50	2 734.4	5	80	2 977.7	1	300
2 404.9	5	50	2 737.1	5	100	2 978.9	1	50
2 405.3	5	50	2 739.2	....	50	2 980.7	3	50
2 405.9	5	50	2 740.2	3	50	2 982.1	10	80
2 412.5	5	100	2 745.7	3	50	2 985.0	2	50
2 413.9	....	300	2 746.1	....	50	2 990.3	5	200
2 414.5	....	100	2 753.0	5	50	2 992.0	1	100
2 417.0	8	200	2 753.1	2	80	2 994.0	....	50
2 418.7	5	500	2 754.5	10	100	2 994.7	100	300
2 421.9	....	80	2 758.8	1	100	3 005.8	1	50
2 433.8	3	100	2 768.1	10	100	3 022.7	5	100
2 436.0	3	50	2 780.2	30	200R	3 024.7	10	200
2 437.4	4	100	2 791.7	3	100	3 028.4	50	200
2 442.1	3	80	2 793.0	10	100	3 032.8	3	300
2 442.7	1	50	2 797.7	10	200	3 035.0	1	100
2 445.8	....	100	2 810.8	3	100	3 039.8	5	300
2 451.9	3	100	2 816.7	2	50	3 048.2	1	50
2 457.0	1	200	2 827.1	8	50	3 049.5	....	150
2 458.1	2	50	2 829.8	3	50	3 055.5	2	100
2 460.4	....	200	2 835.1	5	100	3 064.5	5	200
2 462.1	1	100	2 841.1	10	100	3 065.3	10	200
2 468.7	....	50	2 842.6	10	100	3 071.6	10	50
2 469.4	1	80	2 846.3	10	50	3 076.9	10	50
2 584.0	10	800	2 849.6	2	100	3 080.4	8	100
2 651.1	3	200	2 859.0	1	50	II 3 094.2P*C	100	1000
2 656.1	8	200	2 861.1	10	100	3 097.1	3	100
2 658.0	....	200	2 868.5	15	300	3 127.5	10	50
2 665.3	3	300	2 875.4	50R	300	3 130.8p†C	100	100
2 666.6	5	50	2 876.9	40	500	3 145.4	10	100
2 671.9	20	200	2 880.7	4	50	3 150.4	1	50
2 673.6	10	100	2 883.2	100	800R	3 152.2	2	50
2 675.9	10	100	2 888.8	10	100	3 154.8	3	200
2 677.7	2	50	2 893.1	....	100	3 163.4p†	15	8
2 680.1	4	80	2 897.8	15	150	3 173.2	2	100
2 686.4	2	300	2 899.2	20	500	3 175.9	5	50
2 691.8	10	100	2 900.7	....	100	3 180.3	5	200
2 697.1	10	500	2 908.2	20R	200	3 184.2	5	150
2 698.9	5	200	2 910.6	10	100	3 189.3	10	300R
2 702.2	10	100	2 911.7	8	100	3 191.1	100	300
2 702.5	8	80	2 917.1	10	100R	3 191.4	3	200
2 707.8	3	80	2 927.8B$_1$	200	800R	3 194.3	2	150
2 715.3	2	100	2 931.5	3	50	II 3 195.0p§	30	300

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

COLUMBIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 198.2	1	50	3 390.6	30	50	3 568.0	2	50
3 203.4	8	50	3 395.0	2	50	3 568.5	10	50
3 205.0	10	150	3 396.4	2	150	3 575.8	50	80
3 206.3	10	300	3 397.3	....	50	3 580.3	100	300
3 208.6	3	100	3 402.0	....	50	3 585.0	30	50
3 215.6	50	200	3 403.0	20	80	3 589.1	50	30
3 217.0	2	200	3 405.4	80	50	3 589.4	100	100
3 223.3	10	100	3 408.7	5	50	3 591.2	2	50
3 225.5p	150	800	3 409.2	10	100	3 594.0	80	50
3 229.6	5	50	3 412.9	5	150	3 597.8	50	50
3 236.4	10	200	3 416.0	50	50	3 619.5	5	200
3 237.7	2	50	3 420.6	5	50	3 619.7	3	300
3 238.0	20	200	3 421.2	10	50	3 628.2	1	50
3 247.5	50	100	3 425.4	30R	300	3 651.2	10	400
3 248.9	5	50	3 425.8	50R	30	3 659.6	15	500
3 250.3	5	100	3 426.6	5	200	3 688.0	20	300
3 254.1	20	800	3 432.7	10	100	3 695.9	4	200
3 254.9	1	50	3 437.0	20R	50	3 696.7	2	50
3 260.6	15	300	3 438.4	1	50	3 697.8	50	50
3 261.7	1	50	3 439.9	4	50	3 707.9	3	100
3 263.4	3	500	3 440.6	15	80	3 713.0	100	80
3 273.9	20R	100	3 445.7	50	80	3 717.1	8	1000
3 283.5	2	100	3 448.2	3	50	3 719.6	....	50
3 291.1	10	100	3 450.8	2	50	3 720.5	5	100
3 292.0	3	100	3 452.3	5	200	3 722.6	....	60
3 294.4	2	100	3 454.0	....	100	3 726.2	30	100
3 297.0	3	50	3 454.7	3	50	3 739.8	100	200
3 301.5	1	100	3 454.9	3	80	3 740.7	3	50
3 305.6	1	100	3 463.8	30	50	3 742.4	30	50
3 312.6	40	50	3 468.1	....	50	3 746.9	20	80
3 319.6	4	50	3 470.3	3	100	3 759.6	40	50
3 320.8	3	100	3 474.7	100	7	3 781.4	5	200
3 323.9	1	50	3 478.8	2	50	3 790.2	100R	50R
3 324.7	4	50	3 479.6	5	200	3 791.2	80	80
3 341.6	3	50	3 483.0	2	100	3 798.1	50	80
3 342.0	100R	50	3 484.0	10	100	3 802.9	50	50
3 346.8	5	80	3 489.1	5	50	3 804.7	20	50
3 348.3	1	50	3 491.0	30	50	3 810.5	30	50
3 349.1	80	100	3 498.6	30	50	3 818.9	8	300
3 349.3	5	100	3 499.9	5	50	3 824.9	30	50
3 358.4	100	100	3 510.3	15	200	3 831.8	5	300
3 360.9	3	50	3 511.2	50	1	3 855.5	....	50
3 362.2	....	100	3 514.0	....	50	3 859.0	20	50
3 365.6	5	50	3 515.4	20	300	3 865.0	....	200
3 369.2	5	50	3 517.7	2	200	3 875.8	10	50
3 370.2	....	80	3 522.4	....	50	3 877.6	50	20
3 372.6	10	200	3 528.5	3	50	3 879.3	5	300
3 379.3	1	100	3 535.3	300	500	3 885.4	50	100
3 380.9	....	200	3 541.0	15	500	3 891.3	50	100
3 386.2	5	100	3 541.3	50	5	3 898.3	3	200
3 388.9	1	80	3 559.6	2	100	3 914.7	30	100

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

COLUMBIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 919.7	2	100	4 437.2	40	50	5 276.2	200	50
3 920.2	30	100	4 493.0	1	50	5 318.6	100	12
3 920.8	1	50	4 573.1	30	50	5 334.9	50	10
3 936.0	5	200	4 581.6	30	50	5 344.2	400	200
3 938.5	....	100	4 606.8	50	50	5 350.7	150	50
3 943.7	20	50	4 648.9	50	20	5 376.2	80	5
3 949.5	1	50	4 672.1	150	100	5 642.1	80	20
3 952.4	3	50	4 675.4	50	30	5 664.7	100R	30R
3 964.3	1	50	4 706.1	50	50	5 665.6	100	30
3 967.4	....	50	4 708.3	50	30	5 671.0	200	10
3 976.5	....	80	4 749.7	100	50	5 787.5	80	15
4 000.6	2	50	4 810.6	100	10	5 838.6	200	100
4 012.2	....	100	4 816.4	50	50	5 866.5	50	15
4 032.5	30	50	4 848.4	150	100	5 900.6	200	200
I 4 058.9P¶A_1C	1000	400	4 965.4	100	15	5 997.9	50	5
I 4 079.7p**C	500	200	4 967.8	150	50	6 430.5	80	10
I 4 100.9††A_2	300	200	4 989.0	150	10	II 6 465.0	5	50
4 119.3	2	200	5 017.7	80	10	6 544.6	80	10
I 4 123.8	200	125	5 026.4	50	8	6 660.8	300	80
I 4 137.1p	100	60	5 039.0	200	30	6 677.3	200	50
4 139.7	50	50	5 058.0	50	10	6 701.2	100	15
4 152.6	100	300	5 065.3	80	10	6 723.6	100	30
4 156.7	5	100	5 079.0	300	50	6 739.9	80	15
4 163.7	60	40	5 095.3	50	30	6 828.1	150	30
4 164.7	30	50	5 100.2	100	15	6 876.4	80	12
4 168.1	100	8	5 120.3	50	10	6 902.9	60	10
4 184.4	20	50	5 134.8	200	15	6 918.3	80	10
4 214.7	....	100	5 152.6	100	10	6 990.3	100	15
4 217.9	50	50	5 160.3	200	15	7 046.8	200	40
4 229.1	50	100	5 164.4	150	20	7 098.9	60	10
4 253.0	30	50	5 180.3	150	15	7 159.4	100	15
4 255.4	30	50	5 187.0	50	10	7 353.2	60	10
4 270.7	30	50	5 189.2	80	12	7 382.5	150	30
4 292.5	30	50	5 193.1	100	20	7 574.6	100	20
4 311.3	30	100	5 219.1	100	10	7 726.7	60	....
4 359.9	50	50	5 232.8	50	10	7 885.3	60	....
4 368.0	2	50	5 271.5	200	50			

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Al 3961.5	*Al Bi Cr Cu Mg V Mo Th Ir Fe Ta	A_2Fe 4118.6	
Fe 3222.1		Mo 3170.3	‖Au Ba Co Cr Fe
Mg 2779.9		‖Fe 3719.9	
†Be 2348.6	†Cr Mn Ti V W Rh Ce Th Be U Ta Ba	Mo 3624.5	¶Co Cr Fe Mg Mn Pt Ti W Ir Mo Ca
Cr 2849.8		¶Fe 4059.7	
Hg 3650.2		Mn 4048.8	**Ba Bi Co Cr Cu Fe Mg Mo Ni Pt Sc Sr Ti V Ir Ce Mn
Mo 3864.1		**Mn 4055.6	
Ni 3012.0		Mo 4069.9	
‡Ti 3168.5	‡Cr Mn Mo V W	Sc 4020.4	
Ti 3162.6		Ti 4295.8	††Cr Fe Mn Mo Ni In Ti
§Cr 3180.7	§Au Cr Cu Mn Mo	††V 4095.5	
Fe 3222.1		V 4105.0	
A_1Fe 4118.6		B_1Mn 2933.1	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

COPPER

Cu

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 015.6	....	50	I 2 363.2	10	7	I 3 021.6	25	5
I 2 024.3	50R	6	II +2 369.9LA_3	20	30	I 3 022.6	30	3
II 2 035.8	12	30	2 392.6	250	50	I 3 025.0	30	3
II 2 037.1	12	30	II 2 400.1	5	100	I 3 030.3	10	1
II 2 043.8	15	35	I 2 406.7	150	50	I 3 036.1	200	50
II 2 055.0	15	35	II 2 424.4	4	200	I 3 044.0	20	1
I 2 079.5	15	....	I 2 441.6	200	100	I 3 063.4	300	50
I 2 105.1	15	....	II 2 468.6	5	70	I 3 073.8	70	20
I +2 112.1	15	40	II 2 485.8	5	50	I 3 088.1	30	7
II 2 123.0	15	50	II 2 489.7	3	50	I 3 094.0	150	50
II +2 126.0	15	35	I 2 492.1	200R	50	I 3 099.9	60	10
I 2 130.8	25	3	II 2 506.3	....	500R	I 3 108.6	20	5
II 2 134.4	30	40	II 2 526.6	....	200	I 3 116.3	50	12
II 2 136.0p	25	500	II 2 526.7	....	50	I 3 120.4	25	3
I 2 138.5	25	....	II 2 529.3	....	600	I 3 126.1	80	20
II 2 149.0	15	25	II 2 544.8	....	700R	I 3 128.7	70	15
I 2 165.1	60R	25	II 2 590.5	1	250	I 3 140.3	50	12
I 2 169.5	30	....	I 2 592.6	1000	50	I 3 142.4	60	15
I 2 171.8	30	....	II 2 598.8	....	200	I 3 146.8	100	20
I 2 178.9	30R	12	II 2 600.3	1	200	I 3 149.5	50	2
I 2 181.7	50R	15	I 2 618.4	500	100	I 3 156.6	50	15
II +2 189.6	12	40	I 2 630.0	12	2	I 3 160.0	12	2
II 2 192.3pS_1N_3	25	500	II 2 689.3	....	300	I 3 169.7	50	20
I 2 199.6	50R	20	II 2 701.0	20	400	I 3 194.1	70	60
I 2 199.8	20R	5	II 2 703.2	10	200	I 3 208.2	25	15
II 2 210.3	20	40	II 2 713.5	50	300	I 3 223.4	20	10
I 2 214.6	50R	5	2 715.5	20	....	I 3 224.7	25	10
I 2 215.7	30	....	II 2 718.8	40	300	I 3 231.2	15	10
II +2 218.1	25	40	I 2 720.2	18	....	I 3 235.7	15	7
I 2 225.7	150	20	II 2 721.7	....	150	I 3 243.2	15	15
I 2 227.8	40R	25R	I 2 724.0	50	1	I 3 247.5*pFL	5000R	2000R
I 2 230.1	30R	20	II 2 725.3	30	30	$S_3B_3N_1A_1C$		
I 2 236.3	30	....	I 2 725.5	8	150	I 3 266.0	20	15
I 2 238.5	40	....	I 2 766.4	500	20	I 3 268.3	15	10
II +2 242.6	25	50	I 2 768.9	25	1	I 3 274.0p†	3000R	1500R
I 2 244.3	25	9	II 2 769.7	5	400	$LS_4B_4N_2A_2C$		
II 2 247.0p	30	500	I 2 782.6	20	1	I 3 279.8	25	30
I 2 260.5	25	6	I 2 802.7	10	2	3 280.7	10	2
I 2 263.1	30	10	I 2 824.4B_1	1000	300	I 3 282.7	25	15
II 2 276.3	10	30	II 2 837.5	....	250	I 3 290.5	25	20
I 2 293.8	40	10	I 2 858.2	30	2	I 3 292.8	10	2
II 2 294.4	3	25	I 2 858.7	30	2	I 3 307.9	60	30
I +2 303.1	30	20	I 2 961.2S_2B_2	350	300	I 3 317.2	60	20
I 2 319.6	20	....	I 2 978.3	10	1	I 3 319.7	60	20
II 2 348.8	15	20	2 991.8	15	....	I 3 329.6	60	10
2 354.0	10	....	I 2 997.4	300	30	3 335.2	60	15
II 2 356.7	5	25	I 2 998.4	20	2	I 3 337.8	70	50
2 358.5	12	....	I 3 010.8	250	30	I 3 349.3	70	40
2 361.4	12	....	I 3 012.0	50	6	I 3 354.5	30	10

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

COPPER (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 3 365.3	70	30	I 3 641.7	60	5	II 4 506.0	1	50
I 3 375.7	25	5	I 3 645.2	20	5	I 4 507.5	50	30
I 3 381.4	20	7	I 3 652.4	10	1	I 4 509.4	150	30
I 3 395.5	30	7	I 3 654.3	10	2	I 4 530.8	200	50
I 3 396.3	30	3	I 3 655.9	20	7	I 4 539.7	100	80
I 3 402.2	45	10	I 3 665.7	20	5	II 4 555.9	2	70
I 3 413.3	20	7	I 3 672.0	20	3	I 4 587.0	250	80
I 3 420.2	15	3	3 676.9	25	1	II 4 649.3	....	60
I 3 440.5	10	4	I 3 684.7	12	4	I 4 651.1	250	40
I 3 450.3	150	30	I 3 700.5	20	7	II 4 674.8	200	30
3 454.7	40	10	I 3 712.0	20	4	I 4 697.5	60	5
I 3 457.9	50	15	I 3 720.8	10	1	I 4 704.6	200	50
I 3 459.4	25	2	I 3 741.2	50	2	I 5 016.6	15	....
I 3 465.4	10	2	I 3 743.4	40	40	I 5 105.5p	500	....
I 3 472.1	20	5	I 3 759.5	20	2	I 5 111.9	15	....
I 3 476.0	25	10	I 3 771.9	30	5	I 5 153.2p	600	....
I 3 483.8	60	25	I 3 800.5	20	2	I 5 218.2p	700	....
I 3 487.6	30	5	I 3 805.3	20	2	I 5 220.1	100	....
I 3 488.9	30	5	I 3 820.9	10	3	I 5 292.5	50	....
I 3 498.1	20	5	I 3 825.0	40	3	I 5 700.2	350	....
I 3 500.3	20	2	I 3 861.7	50	2	I 5 782.1	1000	....
I 3 512.1	50	30	I 3 925.3	50	2	II 5 941.2	....	50
I 3 517.0	20	3	I 4 003.1	40	1	6 119.6	25	....
I 3 520.0	30	10	I 4 022.7	400	25	I 6 127.7	80	....
I 3 524.2	40	10	I 4 050.7	30	....	I 6 147.3	20	....
I 3 527.5	50	10	I 4 062.7	500	2	II 6 216.9	....	60
I 3 530.4	50	20	I 4 063.3	30	7	I 6 268.3	40	....
I 3 533.7	50	15	I 4 073.3	15	....	II 6 470.2	....	50
I 3 545.0	35	6	I 4 075.6	40	....	I 6 599.7	25	....
I 3 594.0	15	2	I 4 080.6	30	....	I 6 621.6	20	....
I 3 598.0	40	....	I 4 104.2	30	1	I 6 672.2	15	....
I 3 599.1	60	30	I 4 121.7	20	....	I 6 741.4	50	....
I 3 602.0	50	25	I 4 123.3	30	1	I 6 920.1	100	....
I 3 609.3	20	5	I 4 177.8	60	1	I 7 039.4	15	....
I 3 610.8	25	6	I 4 242.3	20	....	II 7 404.3	....	100
I 3 613.8	60	7	I 4 249.0	80	15	I 7 570.1	50	....
I 3 614.2	50	6	I 4 259.4	25	2	II 7 664.7	5	70
I 3 620.4	30	5	I 4 275.1	80	30	II 7 825.7	....	50
I 3 621.2	20	5	I 4 378.2	200	30	I 7 933.1	150	....
I 3 624.2	30	3	I 4 415.6	40	....	II 7 988.2	....	60
I 3 632.6	25	3	I 4 480.4	200	20	I 8 092.6	400	....
I 3 635.9	50	7						

Control lines:
*Ti 3252.9
†V 3271.1
V 3267.7

Interfering lines:
*Co Cr Fe Mo Mn Sb Ag Ce Cb
†Ca Mo Sc Ce Na Fe Co Cb Ta

Control lines:
S_1Pb 2189.7
S_2Pb 2980.3
S_3Pb 3220.5

Control lines:
B_3Fe 3246.0
Pb 2833.1
Mg 2802.7

Control lines:
3119.2
N_2Sn 3262.3
3223.6

For explanation of control and interfering line symbols see page 445

TABLE VI (*Continued*)

Principal Lines by Elements

COPPER (*Continued*)

Control lines:
3240.2
S_4Pb 3240.2
3220.5
2657.2
B_1Sn 2850.6
Zn 3075.9
B_2Sn 3032.8
3009.1
B_4Fe 3271.0
Sn 3262.3

Control lines:
N_1Sn 3223.6
3218.7
3141.8
Pb 3262.4
3240.2
3220.5
3218.7
3141.8
Pb 3262.4
3240.2

Control lines:
3220.5
3119.5
N_3Sn 2282.2
Pb 2190.0
A_1Zn 3282
Al 3082
A_2Mg 2916
A_3Pb 2628

DYSPROSIUM

Dy

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 135.4	100	50	3 546.8	50	10	3 841.3	100	....
3 141.1	50	20	3 550.2	200	100	3 853.0	100	....
3 156.5	50	20	3 563.2	200	100	3 868.5	50	....
3 162.8	80	60	3 563.7	50	30	3 868.8	60	....
3 170.0	100	50	3 569.0	100	....	3 869.9	100	....
3 251.3	100	100	3 573.8	80	80	3 872.1	300	150
3 280.1	70	5	3 574.2	200	100	3 874.0	100	....
3 312.7	50	5	3 576.3	300	....	3 898.5	100	....
3 316.3	50	4	3 576.9	200	50	3 914.9	50	....
3 319.9	150	9	3 578.0	150	50	3 915.6	80	....
3 340.0	80	4	3 580.0	80	30	3 931.5	200	....
3 368.1	60	5	3 584.4	50	20	3 944.7L	300	150
3 393.6	100	10	3 585.1	300	100	3 950.4	50	....
3 407.8L	150	9	3 585.8	150	100	3 957.8	70	....
3 429.4	50	5	3 591.4	200	100	3 968.4	300	....
3 434.4	80	30	3 591.8	80	20	3 978.6	200	15
3 441.5	50	5	3 592.1	80	30	3 981.9	150	100
3 445.6	80	8	3 595.0	200	100	3 983.7	150	8
3 447.0	50	8	3 596.1	50	20	3 984.2	80	....
3 454.3	100	10	3 606.1	200	100	3 996.7	200	80
3 456.6	50	30	3 618.5	80	10	4 000.5p	400	300
3 461.0	100	3	3 620.2	80	20	4 046.0p	150	12
3 468.4	50	3	3 629.4	100	50	4 073.1	80	15
3 473.7	80	40	3 645.4L	300	100	4 078.0pL	150R	100
3 477.1	90	30	3 648.8	50	30	4 103.3	50	50
3 494.5	100	5	3 672.3	100	100	4 168.0p	50	12
3 498.7	50	50	3 674.1	100	50	4 186.8	100	12
3 504.5	90	3	3 747.8	60	20	4 194.8	50	12
3 505.5	70	2	3 753.5	50	20	4 211.7p	200	15
3 506.8	80	....	3 753.8	80	10	4 214.2	50	8
3 517.3	70	4	3 757.4	200	50	4 218.1	50	8
3 531.7L	100	100	3 788.4	100	40	4 221.1	60	8
3 535.0	125	....	3 806.3	25	80	4 308.6	100	12
3 536.0	125	10	3 816.8	100	50	4 589.4	70	15
3 538.5	150	40	3 836.5	100	40	4 612.3	50	10
3 542.3	90	20						

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

ERBIUM

Er

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 128.1	....	250	3 639.7p	20	12	4 831.1	25	....
2 191.2	....	200	3 692.7p	20	12	5 042.0	60	....
2 327.4	....	150	3 906.3p	25	12	5 256.0	50	....
3 372.8L	35	20	3 988.0	100R	20	5 395.9	50	....
3 499.1p	18	15	4 008.0	35	7	5 414.6	50	....
3 599.8	30	20	4 419.6	25	4	5 826.8	50	....
3 620.2	50	3						

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

EUROPIUM

Eu

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 638.8	300	200	II 3 799.0	100	....	4 718.6	60	2
2 641.3	100	60	I 3 819.7L	500	500	4 736.6	60	....
2 668.3	300	400	3 884.8	50	5	4 739.2	80	....
2 673.4	125	50	II 3 907.1	1000R	500R	4 740.5	500	2
2 678.3	150	100	3 930.4	100	....	4 741.8	10	....
II 2 685.7	150	100	II 3 930.5L	1000R	400R	4 755.9	60	....
2 692.0	200	200	3 943.1	50	15	4 758.7	60	2
II 2 701.1	60	60	3 949.6	50	....	4 762.9	60	2
2 701.9	50	....	3 955.8	50	....	4 938.3	250	....
2 705.3	50	....	3 961.1	50	....	5 013.1	125	1
2 717.0	300	300	3 971.9	100R	....	5 022.9	125	....
2 727.8	300	500	I 3 972.0LA	1000R	....	5 029.5	500	....
II 2 729.4	100	60	4 036.1	50	....	5 033.5	60	2
2 781.9	100	100	II 4 129.7A	150R	50R	5 114.4	150	....
2 802.9	150	....	II 4 205.0pA	200R	50	5 124.8	60	....
II 2 811.7	50	....	4 235.6	400R	....	5 129.1	200	....
2 814.0	300	300	4 322.6	60	....	5 133.5	150	....
2 816.2	50	50	4 329.4	100	2	5 160.1	200	....
2 820.8	200	200	4 330.0	100	1	5 166.7	125	....
2 828.7	200	150	4 331.2	80	....	5 199.8	500	....
2 862.6	100	70	4 337.7	100	2	5 200.9	300	....
2 893.9	150	100	4 345.9	80	1	5 213.4	150	....
2 906.7	300	300	4 354.8	100	2	5 215.1	1000	....
2 925.0	150	100	I 4 355.1	150	20	5 217.0	125	....
2 952.7	200	150	4 370.5	60	2	5 223.5	700	....
2 960.2	150	....	I 4 383.2	100	20	5 239.2	80	....
2 991.3	80	40	4 387.9	200	....	5 248.6	80	....
3 054.9	400	3	4 417.3	60	....	5 249.1	60	....
3 097.5	200	5	4 435.5	2000	....	5 266.4	1000	....
3 111.4	200	....	4 435.6	400R	100	5 272.0	2000	....
3 130.7	100	100	4 465.0	80	10	5 272.5	400	....
3 210.6	80	....	4 522.6	500	....	5 282.8	1000	....
3 212.8	200	20	I 4 522.6	200R	200	5 287.2	125	....
3 213.7	100	20	4 526.7	100	....	5 289.2	125	....
3 247.5	50	5	4 594.0	500R	200	5 291.3	200	....
3 280.7	2000R	....	4 611.5	50	....	5 293.7	50	....
3 334.3	50	5	4 625.3	50	....	5 294.6	300	....
3 396.6	100	10	4 627.2	50	15	5 303.9	300	....
3 425.0	50	4	4 644.2	50	....	5 350.4	60	....
3 521.1	50	4	4 656.7	50	1	5 351.7	150	....
3 602.2	100	50	4 660.4	50	1	5 352.8	80	....
3 606.7	50	....	4 661.9	80	20	5 355.1	200	....
3 622.6	20	50	4 661.9	100	....	5 357.6	1000	....
3 629.8	40	50	4 685.3	60	....	5 360.8	150	....
3 678.3	50	....	4 688.2	100	2	5 361.6	300	....
II 3 688.4	1000	500	4 692.6	60	2	5 370.9	200	....
3 713.5	50	2	4 698.1	300	2	5 392.9	150	....
3 725.0	250	50	4 713.6	400	2	5 402.8	1000	....
3 774.1	50	10	4 717.2	60	2	5 411.8	80	....

For explanation of control and interfering line symbols see page 445

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

EUROPIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
5 421.1	125	....	6 005.7	60	....	6 458.0	500	....
5 426.9	200	....	6 012.2	300	....	6 501.5	300	....
5 443.6	125	....	6 012.6	400	....	6 519.6	500	....
5 451.5	1000	....	6 015.6	150	....	6 567.9	600	....
5 453.0	1000	....	6 018.2	1000	....	6 593.8	400	....
5 472.3	1000	....	6 023.2	200	....	6 603.6	80	....
5 488.6	500	....	6 029.0	500	....	6 645.2	1000	....
5 495.2	125	....	6 044.7	200	....	6 685.3	80	....
5 510.5	300	....	II 6 049.5	1000	....	6 694.0	500	....
5 526.6	60	....	6 057.4	600	....	6 745.0	100	....
5 542.5	80	....	6 075.6	300	....	6 782.6	100	....
5 547.4	1000	....	6 077.4	100	....	6 802.8	500	....
5 570.4	1000	....	6 083.9	500	....	6 816.1	150	....
5 577.1	1000	....	6 099.4	600	....	6 841.1	50	....
5 579.6	200	....	6 108.1	150	....	6 864.6	1000	....
5 580.0	200	....	6 118.8	400	....	6 903.7	200	....
5 586.2	300	....	6 124.7	150	....	7 040.2	800	....
5 586.8	200	....	I 6 173.0	600	....	7 074.6	60	....
5 618.8	125	....	6 178.7	120	....	7 077.1	800	....
5 622.4	200	....	6 188.1	500	....	7 106.5	600	....
5 632.6	200	....	6 195.1	300	....	7 164.7	50	....
5 645.8	1000	....	6 233.7	100	....	7 175.5	200	....
5 673.8	200	....	6 250.5	70	....	I 7 194.9	700	....
5 684.3	125	....	6 262.3	600	....	I 7 217.6	700	....
5 730.9	300	....	6 266.9	120	....	7 224.7	150	....
5 739.0	300	....	6 288.3	300	....	7 258.7	100	....
5 765.2	2000	....	6 291.3	250	....	7 262.8	200	....
5 783.7	150	....	6 299.8	500	....	7 281.6	50	....
5 800.3	200	....	II 6 303.4	700	....	II 7 301.1	700	....
II 5 818.7	1000	....	6 335.8	200	....	7 313.6	60	....
5 831.0	2000	....	6 350.0	600	....	7 336.3	300	....
II 5 873.0	300	....	6 355.9	200	....	7 362.3	50	....
5 891.3	200	....	6 369.2	300	....	7 369.7	200	....
5 915.8	200	....	6 382.7	200	....	I 7 370.3	700	....
5 926.5	80	....	6 383.9	350	....	7 426.6	500	....
5 963.8	60	....	6 400.9	700	....	7 436.6	100	....
5 966.1	1000	....	6 406.1	100	....	7 528.7	200	....
5 967.2	2000	....	6 410.1	500	....	7 583.9	400	....
5 972.8	300	....	6 411.3	500	....	7 742.6	400	....
5 992.9	1000	....	6 428.3	200	....	7 746.2	600	....
6 004.4	300	....	I 6 437.7	700	....	7 888.0	300	....

Control lines:
A Sm 3971.3
3972.2
4129.2
4130.0
4204.8
4205.3

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

GADOLINIUM

Gd

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 796.9	70	80	3 674.1	100	30	4 053.3	100	80
2 809.7	60	80	3 684.1	200	150	I 4 053.6	100	40
2 840.2	50	60	3 686.3	150	200	I 4 054.7	80	20
3 010.1	100	100	3 687.8	200	200	I 4 058.2	100	60
3 027.6	100	60	3 697.7	200	200	4 059.9	50	20
3 032.9L	100	100	3 699.7	200	250	4 065.6	50	50
3 034.1L	100	60	3 712.7	200	250	4 070.3	80	....
3 068.6	50	50	3 713.6	100	80	4 073.2	80	80
3 082.0	100	60	3 716.4	150	125	4 073.8	100	50
3 100.5	100	80	3 717.5	100	50	4 085.6	100	80
3 145.0	50	30	3 722.0	50	30	4 087.7	80	100
3 331.4	100	80	3 725.5	50	50	I 4 090.4	100	20
3 350.5	150	180	3 730.9	100	100	I 4 092.7	100	40
3 358.6	100	100	3 739.8	100	50	4 098.9	100	100
3 362.2	150	180	3 740.0	50	50	4 130.4	200	10
3 407.6	100R	100	3 768.4p	20	20	4 131.5	50	50
3 417.0	50	30	3 769.5	50	40	4 162.7	50	....
3 418.7	50	25	3 770.7	50	50	4 170.1	50	50
3 422 5	80	100	3 782.3	25	50	4 175.5	50	....
3 433.0	50	40	3 796.4	150	150	4 184.3	150	150
3 439.2	60	35	3 812.0	200R	200	4 190.1	100	....
3 439.8	50	50	3 814.0	100	60	I 4 190.8	100	40
3 440.0	70	50	3 836.5	100	60	4 191.1	100	....
3 450.4	100	100	3 852.5	100	8	4 197.7	50	50
3 451.2	50	40	3 894.7	150	80	4 212.0	150	50
3 454.9	25	20	3 902.4	100	80	4 215.0	200	150
3 464.0	100	125	3 905.7	50	50	4 217.2	100	100
3 467.3	100	100	3 907.1	100	100	4 225.9	150	50
3 469.0	150	150	3 916.6	150	100	4 227.1	50	20
3 473.2	50	40	1 3 934.8	100	50	4 228.8	200	200
3 481.4	150	150	3 942.6	60	30	4 243.8	60	100
3 481.8	80	60	3 945.5	200	150	4 246.5	150	3
3 492.0	50	25	3 952.0	100	60	4 251.7	300	10
3 494.4	70	60	1 3 953.4	100	50	4 253.4	50	4
3 505.5	60	60	3 957.7	300	200	4 253.6	50	50
3 545 8	125	125	3 963.7	50	60	4 262.1	150	10
3 549.4	125	125	3 969.3	200	....	4 266.6	50	....
3 558 5	100R	50	3 974.0	55	....	4 274.2	100	....
3 585 0	100	100	I 3 979.3	100	30	4 280.5	200	100
3 592 7	50	70	3 987.2	100	100	4 285.8	60	20
3 604 9	50	12	3 987.8	50	25	4 286.1	60	20
3 608 8	100	125	3 996.3	100	100	4 289.9	40	100
3 629.5	40	60	4 001.2	80	3	4 296.1	200	4
3 646 2p	200	150	4 009.2	50	2	4 297.2L	100	4
3 654.6	200	200	4 037.3	100	30	4 304.9	100	100
3 656 2	200	200	4 037.9	100	30	4 306.4	200	80
3 662.3	200	200	4 047.8	150	50	4 311.0	100	....
3 664 6	200	200	4 049.4	80	20	4 313.9	200	80
3 671 2	150	100	4 049.9	100	60	4 314.4	100	20

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

GADOLINIUM (*Continued*)

Wavelength	Arc	Spark
4 316.1	150	60
4 320.5	60	20
4 321.1	50	20
4 322.2	50	25
4 324.1	100	....
I 4 325.7	500R	250
4 327.1	500R	100
4 329.6	100	100
4 330.6	100	....
4 337.5	50	50
4 341.3	200	125
4 342.2L	200	200
4 346.5	150	60
4 346.6	50	20
4 347.3	100	100
4 360.9	200	....
4 369.2	50	20
4 369.8	250	150
4 373.8	200	80
4 380.6	100	125
4 387.7	150	....
4 391.0	100	100
4 392.1	100	100
4 397.5	100	5
4 401.9	200	100
4 403.1	100	100
4 406.7	70	200
4 408.3	100	150
4 411.2	100	50
4 414.2	100	60
4 414.7	100	50
4 419.0	200	200
4 421.2	100	8
4 422.4	100	40
4 426.1	50	2
4 430.6	150	40
4 431.8	60	1
4 436.2	30	100
4 438.3	40	100
4 446.5	80	2
4 466.6	200	150
4 467.1	50	....
4 471.3	50	....
4 474.1	150	150
4 476.1	100	....
4 478.8	80	....
4 481.1	70	100
4 483.3	80	125
4 486.4	25	80
4 486.9	100	15
4 497.1	150	80
4 498.3	100	....
4 506.2	100	50
4 506.3	80	5
4 506.9	50	20
4 514.5F	60	10
4 519.7	150	100
4 520.1	50	3
4 522.8	50	4
4 537.8	150	100
4 540.0	80	200
4 542.0	50	50
4 548.0	50	50
4 614.5F	50	25
4 680.1	50	25
4 683.3	100	50
4 694.3	50	8
4 697.5	100	4
4 702.3	50	100
4 703.1	50	20
4 709.8	100	25
4 719.1	50	20
4 723.7	100	200
4 726.7	40	100
4 728.5	150	100
4 732.6	300	300
4 734.4	100	40
4 735.8	150	150
4 738.1	50	50
4 743.7	300	300
4 767.3	100	25
4 781.9	200	50
4 784.6	100	50
4 791.6	150	....
4 801.1	200	200
4 802.6	100	40
4 803.6	100	40
4 805.8	200	80
4 807.5	100	40
4 816.8	50	20
4 821.7	150	80
4 834.2	125	25
4 835.3	100	10
4 848.1	60	10
4 856.2	80	....
4 856.7	80	....
4 859.2	50	....
4 861.8	100	....
4 862.6	100	2
4 865.0	400	10
4 866 4	100	....
4 870.0	200	10
4 871.5	100	....
4 873.4	200	2
4 876.0	100	10
4 881.0	60	....
4 881.4	50	....
4 881.9	100	20
4 883.2	100	....
4 889.2	60	....
4 894.3	200	4
4 930.7	80	....
4 938.6	150	2
4 942.6	100	....
4 958.8	125	4
4 961.5	100	....
4 965.1	100	10
4 969.2	100	....
5 010.8	50	....
5 015.1	100	....
5 050.9	50	....
5 125.5	50	....
6 305.1	100	....
6 381.0	100	....
6 382.2	60	....
6 422.4	50	....
6 462.6	50	....
6 538.1	50	....
6 634.4	150	....
6 645.2	150	....
6 681.2	100	....
6 727.8	50	....
6 730.8	100	....
6 752.7	300	....
6 753.9	100	....
6 786.3	125	....
6 820.9	50	....
6 828.3	150	....
6 846.6	500	....
6 857.1	200	....
6 900.7	60	....
6 916.6	200	....
6 985.9	200	....
6 991.9	150	....
6 996.8	200	....
7 006.2	80	....
7 037.3	50	....
7 122.6	50	....
7 147.4	50	....
7 168 4	500	....
7 172 3	50	....
7 189 6	80	....
7 194.9	50	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

GADOLINIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
7 233.4	80	....	7 301.2	150	....	7 418.0	50	....
7.252.7	80	....	7 313.3	150	....	7 426.6	80	....
7 262.7	80	....	7 324.9	80	....	7 441.9	200	....
7 291.4	60	....	7 370.3	80	....	7 464.4	200	....

GALLIUM

Ga

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 659.9C	5	12	I 2 943.6†LC	10	20	I 4 172.1P§FC	2000R	1000R
2 719.7C	5	15	2 944.2LC	10	15	6 396.6	....	20
I 2 874.2*LC	10	15	I 4 033.0p‡FLC	1000R	500R	6 414.0	....	15

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Cr 2865.1	*Ag Cu Fe Pb Ti V	†Fe 2912.2	†Bi Co Cr Fe Mg Mn Ta U Ni Ga V Ir
Fe 2941.3		V 2808.8	
Mo 2848.2		‡Mn 4030.8	‡Co Cr Fe Mo Sb Sr Ti Ta Mn Th Cb
Pb 2814.2		V 4005.7	
Sb 2698.1		§Os 4112.0	§Au Co Cr Fe Mo Mn

GERMANIUM

Ge

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 041.7	5R	150R	2 709.7‡C	30	20	4 179.0	....	25
2 043.8	4R	70	2 754.6§C	30	20	I 4 226.6p	200	50
2 068.7	5R	200R	I 3 039.1p‖LC	1000	1000	II 4 741.9	....	50
2 592.5C	20	15	3 067.0	60	40	II 4 814.8	....	200
I 2 651.2p†C	40	20	I 3 124.8	200	80	II 5 131.7	....	100
I 2 651.6pC	30	20	3 255.3	....	100	II 5 178.6	....	100
2 691.3C	25	15	I 3 269.5pC	300	300	II 5.893.5	....	100

Control lines	Interfering lines:	Control lines:	Interfering lines:
Mn 2576.1		V 2730.7	
†Al 2660.3	†Al Be Hg Mg Mn Mo Fe V Ce Ta Ge Pt	§Cr 2750.7	§Co Fe Pt
Be 2348.6		Fe 2749.3	
Cr 2663.4		‖Cr 3053.9	‖Fe Hg Mo Pt W Ca Ir U V Th Co Ni
‡Mn 2705.7	‡Mn Mo Tl W	Fe 3047.6	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

GOLD

Au

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 012.0	15	18	I 2 905.9	10	30	3 836.5	30	30
2 110.8	....	60	2 907.1	....	25	3 871.4	25	20
I 2 176.3	15	....	II 2 913.5	....	50	I 3 897.9	30	25
2 201.4	....	30	I 2 932.2	8	40	I 3 909.4	10	15
II 2 229.0	....	50	2 954.4	....	50	3 914.2	10	4
2 242.7	....	30	II 2 990.3	....	50	I 3 914.7	15	3
I 2 283.3	15	....	II 2 995.0	....	100	II 4 016.1	10	15
II 2 291.5	....	15	I 3 029.2	25	30	I 4 040.9	50	40
II 2 304.8	....	30	3 033.2	25	30	II 4 052.8	....	60
2 314.7	....	15	I 3 122.8S_5	500	5	I 4 065.1	50	30
II 2 352.7S_1	25	....	I 3 147.6	10	....	I 4 084.1	25	12
I 2 364.6	20	8	I 3 194.7	25	20	I 4 241.8	40	30
I 2 376.2	25	3	I 3 204.7	50	30	I 4 315.1	40	18
I 2 387.8	30	10	I 3 230.6	15	80	I 4 437.3	50	10
I 2 404.8	20	4	3 267.1	10	8	I 4 488.3	40	30
I 2 428.0P*	400R	100	I 3 308.3	50	15	I 4 607.3	30	15
LS$_2$C			I 3 320.2	20	5	I 4 792.6	200	60
I 2 491.2	10	5	I 3 323.2	10	5	I 4 811.6	50	15
2 503.3	....	30	3 349.4	15	5	I 5 064.6	40	10
I 2 510.5	25	15	I 3 355.1	25	....	I 5 147.4	40	5
I 2 544.2	30	8	I 3 553.6	20	10	I 5 230.3	40	15
I 2 590.0	30	50	I 3 565.9	20	15	I 5 261.8	40	3
I 2 641.5	5	20	3 580.1	20	15	I 5 655.8	35	5
I 2 676.0p†	250R	100	3 586.7	20	15	I 5 721.3	15	....
FLS$_3$C			3 592.0	15	5	I 5 726.8	35	10
2 687.6	....	15	3 594.2	25	6	I 5 837.4	400	10
I 2 688.7	2	20	I 3 598.1	35	10	I 5 862.9	30	5
I 2 700.9	20	25	II 3 633.2	1	15	I 5 957.0	35	8
I 2 748.3S_4	40	80	II 3 642.8	10	5	5 962.7	35	3
2 780.8	....	20	3 682.9	20	10	II 6 022.7	15	5
2 802.2	....	200	I 3 695.9	20	3	I 6 160.1	20	....
2 820.0	....	150	3 706.8	....	15	6 162.2	10	5
2 822.7	....	80	II 3 804.0	25	150	I 6 278.2	700	20
2 825.5	10	40	3 816.1	20	40	II 6 456.5	10	5
2 838.0	....	80	II 3 825.6	20	30	I 6 652.6	15	....
I 2 883.5	15	20	3 829.4	25	20	I 7 510.8	20	....
I 2 892.0	8	20						

Control lines:
*Sn 2706.5
W 2431.0
W 2435.9
†Cr 2835.6

Interfering lines:
*Ag Mn Pb Pt Sb Sn Sr Ta U Ir W

†Co Cu Fe Sb V W Rh Mn Cb Ta U

Control lines:
Pt 2650.9
Ta 2685.1
V 2677.8
V 2679.4

Control lines:
S_1Pb 2253.9
S_2Pb 2411.8
2428.8

Control lines:
S_3Pb 3240.2
3262.4
2657.2
2926.8

Control lines:
S_4Pb 2657.2
S_5Pb 3240.2
3119.1

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

HAFNIUM

Hf

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 088.8	50	50	II 2 683.4	15	100	II 3 410.2	25	60
II 2 096.2	100	150	II 2 712.4	25	50	II 3 505.2	20	50
II 2 107.5	60	60	II 2 738.8	40	100	II 3 535.5	15	50
II 2 124.6	50	80	II 2 751.8	25	80	II 3 569.0	20	50
II 2 129.1	60	100	2 753.6	....	60	II 3 644.4	25	50
II 2 178.9	60	80	II 2 773.4	25	60	II 4 093.2	25	20
II 2 254.0	60	80	II 2 774.0	25	50	II 4 336.7	30	60
II 2 255.2	40	60	II 2 820.2	40	100	II 4 417.4	25	50
II 2 266.8	60	80	II 2 822.7	30	90	4 540.9	50	2
II 2 273.2	40	60	II 2 849.2	30	100	4 620.9	50	4
II 2 277.2	150	150	II 2 851.2	25	50	II 4 622.7	20	60
II 2 298.3	25	50	II 2 852.0	20	50	4 655.2	50	4
II 2 321.1	50	60	II 2 861.0	40	90	II 4 664.1	50	100
II 2 322.5	60	60	II 2 861.7	50	125	II 4 934.5	40	50
II 2 323.3	40	60	2 866.4	50	12	II 5 040.8	100	150
II 2 324.9	40	80	II 2 876.3	30	100	II 5 247.1	40	60
II 2 333.0	40	50	I 2 898.3	50	12	II 5 265.0	50	80
II 2 343.3	60	80	II 2 898.7	25	50	II 5 298.1	80	100
II 2 347.4	80	125	I 2 904.4	30	6	II 5 311.6	100	150
II 2 351.2	100	150	I 2 916.5	50	15	II 5 842.2	50	80
II 2 380.3	30	60	II 2 919.6	40	80	II 6 249.0	80	100
II 2 393.4	50	80	II 2 929.6	30	50	II 6 542.8	3	50
II 2 393.8	80	100	II 2 937.8	50	100	II 6 557.9	10	100
II 2 405.4	25	50	I 2 940.8	60	12	II 6 567.4	6	60
II 2 433.6	15	50	2 964.9	50	10	II 6 644.6	100	200
II 2 447.3	25	50	II 2 975.9	80	100	II 6 647.1	30	100
II 2 460.5	20	50	2 980.8	50	10	II 6 719.4	2	50
II 2 464.2	30	100	3 005.6	50	8	II 6 754.6	60	100
II 2 469.2	20	50	II 3 012.9	80	100	6 789.3	50	100
II 2 478.6	100	300	3 018.3	60	10	6 818.9	100	200
2 495.2	....	60	II 3 031.2	70	90	6 850.1	20	60
II 2 513.0	25	70	3 050.7	50	150	II 6 855.3	7	50
II 2 516.9	35	100	3 057.0	70	10	6 868.7	15	50
II 2 531.2	25	50	I 3 072.9	80	18	6 911.4	15	50
II 2 573.9	25	100	II 3 080.7	30	100	II 6 935.2	5	50
II 2 576.8	5	60	II 3 101.4	60	90	II 6 980.9	100	200
II 2 606.4	25	50	II 3 109.1	50	100	II 7 030.3	30	150
II 2 607.0	30	80	II 3 134.7	80	125	7 119.5	15	50
II 2 613.6	20	80	II 3 145.3	50	20	7 131.8	150	250
II 2 622.7	30	80	II 3 352.1	30	50	7 237.1	100	200
II 2 638.7	40	100	II 3 395.0	20	50	7 240.9	70	150
II 2 641.4	40	125	II 3 399.8	60	100	II 7 277.7	5	50
II 2 647.3	40	125						

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

HOLMIUM

Ho

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 636.5	....	70	3 598.8	40	30	4 254.4	100	20
2 774.7	....	300	3.748.2	60	40	4 350.7	40	15
2 834.4	5	40	3 757.3	40	30	5 566.5	100	....
2 845.6	....	70	3 796.7	20	40	5 640.6	100	....
2 928.8	....	100	3.810.7	20	40	5 674.7	200	....
2 936.8	....	1000R	3.861.7	40	20	5 691.5	200	....
2 945.8	3	70	3 889.0	40	20	5 706.9	50	....
3 181.5	8	40	3 891.0	200	40	5 860.3	200	....
3 399.0	40	60	4 040.8	150	30	5 883.0	200	....
3 425.4	40	40	4 045.4	200	80	5 892.6	50	....
3 428.1	40	40	4 053.9	400	200	5 921.8	200	....
3 456.0	60	60	4 103.8	400	400	5 933.7	200	....
3 474.3	40	20	4 108.6	100	40	5 948.0	200	....
3 484.7	40	30	4 120.2	50	25	5 956.0	100	....
3 494.8	30	40	4 127.2	150	60	5 973.5	125	....
3 515.6	40	40	4 163.0	100	100	5 982.9	200	....
3 556.8	15	40	4 173.2	50	....			

INDIUM

In

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 306.9	25	30	I 2 836.9	80	80			
I 2 389.5	50R	....	I 2 932.6	500	300	4 511.3P§LC	5000R	4000R
II 2 447.9	....	80	I 2 957.0	50	25	4 612.1	....	150
I 2 468.0	25	2	3 008.3	....	500	4 638.9	3	70
I 2 521.4	30	....	I 3 039.4*FC	1000R	500R	4 682.0	....	250
I 2 560.2	150R	50R	I 3 256.1†FLC	1500R	600R	5 644.9	....	70
I 2 601.8	50R	15	I 3 258.6LC	500R	300R	I 5 709.8	50	....
I 2 710.3	800R	200R	4 024.8	....	100	I 5 728.3	50	....
I 2 713.9	200R	125	4 057.9	80	10	I 6 847.8	60	....
I 2 753.9	300R	300	4 072.4	....	200	I 6 900.4	50	....
I 2 775.4	80	30	I 4 101.8p‡FC	2000R	1000R			

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Cr 3053.9	*Co Fe Ge Sb W U Cd Cr Ir	Ti 3252.9	
Fe 3047.6		‡Cb 4079.7	‡Cr Fe Mn Mo Ni
Ni 3057.6		V 4095.5	
Pt 2830.3		§Ti 4522.8	§Al Ce Ca Cr Cu Mg Cd Ta Sn Th Pb Pt Ti V W
†Cd 2288.0	†Bi Fe Mn Mo Pt Ce Th Ca Ta Sc		

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

IRIDIUM

Ir

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 017.4	....	50	2 326.1	6	50	3 133.3††LS$_8$G$_7$C	40	2
2 021.5	....	50	2 329.4	5	50	I 3 140.4	50R	1
2 022.8	4	50	2 353.1	4	50	I 3 159.2	50R	2
2 044.2	10	100	2 363.0	50	25	I 3 220.8P‡‡LS$_9$G$_8$ C	100	3
2 044.8	4	75	2 368.0	25	125	I 3 241.5	100	50
2 051 2	10	50	I 2 372.8L	100	40	I 3 266.4	50	10
2 063.0	....	80	2 381.8	8	50	I 3 437.0p	20	15
2 070.5	6	60	2 382.5	....	100	I 3 449.0	60	10
2 080 6	....	80	2 383.0	8	80	I 3 513.6p§§C	100	100
2 088.8	50	50	2 384.8	4	80	I 3 522.0	....	50
2 103 9	....	50	2 386.9	50	15	I 3 559.0	50	50
2 109.4	3	50	2 391.2	50	....	I 3 573.7	8	100
2 117.7	10	50	2 398.7	10	150	I 3 617.2	50	15
2 126.8	25	200	2 431.9	50	50	I 3 628.7	100	30
2 130.5	5	80	I 2 475.1	100	10	I 3 636.2	50	25
2 131.7	....	50	I 2 481.2	50	10	3 653.2	15	50
2 132.7	3	80	I 2 503.0	100	5	I 3 661.7	50	30
2 148.2	25	50	I 2 533.1	100	20	I 3 664.6	60	15
2 151.6	2	80	I 2 534.5	100	10	I 3 675.0	100	50
2 152.7	50	200	I 2 544.0*C	200	100	I 3 725.4	50	20
2 158.1	50	50	I 2 546.0	100	20	3 728.0	60	10
2 160.7	10	50	I 2 577.3	60	15	3 731.4	50	50
2 169.4	2	50	I 2 592.1	100	20	3 734.8	100	30
2 179.0	10	50	I 2 608.2	50	10	3 738.5	60	10
2 190.4	....	150	I 2 611.3	80	10	I 3 747.2	100	60
2 196.4	5	50	I 2 639.7†C	100	15	I 3 767.7	60	10
2 197.5	5	100	I 2 662.0	150	15	3 790.5	50	....
2 198 9	50	15	I 2 664.8‡C	200	50	3 800.1	150	100
2 209.0	2	50	I 2 669.0	50	5	3 833.9	50	....
2 212.3	....	50	I 2 669.9	60	10	3 915.4	150	50
I 2 220.4	50	10	I 2 671.8	50	10	I 3 934.8	200	50
2 221 1	2	100	I 2 694.2§S$_1$G$_1$C	150	50	I 3 946.3	50	15
2 232 2	30	50	I 2 824.4C	20	15	I 3 976.3	10	70
I 2 233 4	9	100	I 2 836.4S$_2$G$_2$	25	10	I 3 992.1	150	60
2 234.4	5	80	I 2 839.2S$_4$	12	....	4 020.0	80	100
2 237 1	....	100	I 2 840.2S$_3$G$_3$	15	10	4 033.8	100	25
2 238 3	....	80	I 2 849.7p¶C	40	20	4 092.6	60	20
2 240 6	....	100	I 2 924.8**LS$_5$G$_4$C	25	15	4 100.1	100	3
2 242 7	50	300	I 2 934.6S$_6$G$_5$	15	6	4 115.8	100	30
2 245 8	10	150	I 2 936.7S$_7$G$_6$	15	5	4 117.6	50	3
2 246 9	10	100	I 2 996.1	50	2	4 155.7	80	5
2 257 5	2	50	I 3 002.3	50	10	4 166.0	150	10
I 2 258 5	15	50	I 3 003.6	60	30	I 4 172.6	150	12
2 265.2	5	50	I 3 025.8	50	3	4 182.5	50	6
2 281 0	2	50	I 3 029.4	60	3	4 259.1	200	10
2 290 8	3	50	I 3 032.4	50	1	I 4 265.3	60	2
I 2 304 2	100	....	I 3 047.2	50	20	I 4 268.1	200	15
2 323 6	....	50	I 3 088.0	50	2	4 286.6	200	3
2 324 7	5	80	I 3 120.8	50	2			

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

IRIDIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Sp
4 301.6	200	10	4 426.3	400	10	4 568.1	100	
4 310.6	150	8	4 450.2	60	3	4 570.0	50	
4 311.5	300	10	4 478.5	200	10	4 616.4	200	
4 351.3	50	....	4 495.3	100	3	4 656.2	60	..
4 352.6	50	2	4 532.9	80	2	4 728.9	150	
4 377.0	100	4	4 545.7	200	4	4 778.2	50	
4 392.6	100	4	4 548.5	100	5	I 6 830.0	50	..
4 399.5	400	100	4 550.8	80	....	I 6 929.9	50	..
4 403.8	300	10						

Control lines:	Interfering lines:
*Co 2535.9	*Au Fe Co Cs Mn Na
Co 2564.0	
†Au 3029.2	†Al Cd Cr Fe Mn Mo
Mn 2638.2	
‡Co 2587.2	‡Au Fe Mo Pb Pt
Cr 2762.6	
Pb 2873.3	
§Fe 2704.0	§Au Fe Mn W
Cu 2961.2	
Fe 2844.0	
¶Cr 2843.3	¶Cr Fe Ni Pd Sb Sn W Ta Co U Mo

Control lines:	Interfering lines:
Fe 2844.0	
Mg 2802.7	
**Mo 2891.0	**Co Cu Hg Mn Mo Tl
††Be 2348.6	††Au Be Cd Cr Hg Mo Sc
Cr 2849.8	
Hg 3650.2	
Ni 3012.0	
‡‡Fe 3225.8	‡‡Mn Mo Pb Ce Cb W Th F
Ti 3242.0	
§§Co 3409.2	§§Ag Ce Co Cu Fe Mo Ni U Ta Rh
Fe 3521.3	
Ni 3619.4	

Control lines:
S_1Pt 2698.4
S_2Pt 2834.7
S_3Pt 2834.7
S_4Pt 2834.7
S_5Pt 2919.3
2921.4
S_6Pt 2919.3
2921.4
S_7Pt 2919.3
2921.4
S_3Pt 3156.6

Control lines:
S_9Pt 3301.9
3204.1
3200.7
3156.6
3230.3
3212.5
G_1Pt 2698.4
G_2Pt 2834.7
G_3Pt 2834.7
G_4Pt 2919.3
2921.4

Control lines:
G_5Pt 2919.3
2921.4
G_6Pt 2919.3
2921.4
G_7Pt 3156.6
G_8Pt 3301.9
3204.1
3200.7
3230.3
3233.4
3212.5

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

IRON

Fe

	Wavelength	Arc	Spark		Wavelength	Arc	Spark		Wavelength	Arc	Spark
	2 020.52	2	100		2 170.54	10	....	I	2 255.860	20	....
I	2 100.795	15	2	I	2 171.292	10	3	I	2 259.279	6	....
I	2 102.349	15	3	I	2 173.211	8	2	I	2 259.511	25	....
	2 107.13	8	....	I	2 175.447	8	25	II	2 260.079	9	15
I	2 108.202	5	4	I	2 176.837	8	....		2 260.600	10	....
I	2 108.955	10	2	I	2 178.091	100R	20	II	2 260.853	12	12
I	2 115.168	8	....		2 178.952	8	....	II	2 262.680	6	12
	2 121.94	6	....	I	2 180.866	8	....	I	2 263.474	6	....
	2 125.01	30	....		2 183.47	6	....	I	2 264.389	35	5
	2 127.87	5	....		2 183.977	20	....	I	2 265.050	10	....
	2 130.42	5	....	I	2 186.241	5	....	I	2 266.899	15	....
	2 130.962	20	....		2 186.485	50R	80	I	2 267.466	15	....
I	2 132.015	12	3		2 186.890	6	12	I	2 269.097	12	....
	2 135.957	10	5	I	2 187.191	50R	10		2 270.860	10	....
I	2 138.589	8	....		2 189.18	6	....	I	2 271.780	35	....
I	2 139.695	8	8		2 190.772	20	2	I	2 272.067	15	3
	2 141.471	10	....	I	2 191.202	10	2	I	2 272.816	20	....
	2 143.90	8	....	I	2 191.833	100R	12	I	2 274.088	15	15
	2 144.45	25	....		2 192.82	5	....		2 275.187	10	....
	2 145.188	12	2		2 193.411	8	....	I	2 275.595	8	....
	2 147.04	8	....	I	2 196.039	80R	30	I	2 276.024	20	10
	2 147.787	8	....		2 199.573	10	....	I	2 277.096	15	....
	2 148.50	5	....	I	2 200.39	50R	100	I	2 277.672	25	....
	2 149.17	10	....	I	2 200.722	35	8	I	2 279.924	15	40
I	2 150.182	8	2	I	2 201.117	10	....	I	2 280.220	15	....
I	2 151.099	8	10	I	2 207.068	6	....		2 281.99	6	....
	2 151.70	20	....		2 208.016	5	....	I	2 282.863	8	....
	2 151.897	5	....	I	2 210.686	8	....	I	2 283.305	8	....
	2 152.24	8	....	I	2 211.234	6	....	I	2 283.653	10	....
I	2 153.004	10	1	I	2 213.654	2	35	I	2 284.085	25	20
	2 154.458	15	....		2 221.83	12	....	I	2 287.248	20	6
	2 155.64	8	....		2 222.763	5	5	I	2 287.630	5	....
	2 155.81	5	....	I	2 228.168	10	6	I	2 289.031	25	....
	2 156.47	20	....		2 229.07	6	....	I	2 290.065	10	....
	2 157.792	10	4	I	2 231.211	8	....	I	2 290.545	15	....
I	2 158.48	12	8		2 236.313	10	....	I	2 290.768	6	....
I	2 159.650	8	3	I	2 238.259	5	....	I	2 291.120	15	....
I	2 159.893	12	2		2 240.627	20	3	I	2 291.624	10	2
I	2 161.577	6	....		2 241.840	6	2	I	2 292.523	15	2
I II	2 162.022	5	25		2 245.654	12	....		2 293.846	10	6
				II	2 246.907	....	20	I	2 294.406	15	2
	2 162.24	10	....	II	2 247.692	....	50	II	2 294.612	15	5
	2 163.366	12	....	I	2 248.857	35	....	II	2 296.666	5	....
	2 163.860	8	1	II	2 249.175	10	50	I	2 296.925	15	2
	2 164.39	8	....	II	2 250.169	5	15	I	2 297.786	35R	6
	2 165.860	20	1	I	2 250.776	10	....	I	2 298.17	5	....
I	2 166.773	100R	35	II	2 250.930	5	20	II	2 298.231	5	25
	2 168.38	8	3	I	2 251.872	12	70		2 298.662	8	2
	2 169.946	8	....	II	2 253.124	12	30	I	2 299.218	15	4

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

IRON (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 299.455	8	....	II 2 383.055	6	2	2 460.596	15	....
I 2 300.139	15	3	II 2 383.241	8	12	2 461.056	20	....
2 300.59	8	....	2 384.386	20	5	II 2 461.857	15	70
I 2 300.778	20R	4	II 2 385.007	8	15	I 2 462.180	50R	3
2 301.173	10	....	2 387.279	6	....	I 2 462.644	200R	50
I 2 301.681	15	....	II 2 388.627	25	30	2 463.507	5	....
2 303.422	10	....	I 2 389.971	15	....	I 2 463.728	15	7
I 2 303.578	10	3	II 2 391.474	8	....	II 2 464.007	5	80
I 2 304.729	10	20	II 2 395.408	6	5	II 2 464.903	4	50
I 2 306.171	10	....	II 2 395.625p†			I 2 465.148	70	....
2 306.380	10	3	S_2C	50	100	II 2 465.200	....	50
I 2 309.997	20	5	II 2 399.236	20	30	2 465.455	15	....
I 2 313.102	25	3	II 2 402.600	10	20	I 2 467.730	10	2
2 317.889	8	....	II 2 404.430	25	40	2 468.878	40	15
2 318.17	10	....	II 2 404.882pS_3	50	100	II 2 470.658	8	50
I 2 320.356	25	5	II 2 406.658	50	1	I 2 470.966	20	1
II 2 327.394	10	25	2 407.229	20	2	2 472.106	9	....
I 2 329.630	5	....	I 2 408.045	10	....	I 2 472.344	30	5
II 2 331.306	10	6	II 2 410.517p	50	70	I 2 472.880	300R	25
II 2 332.796	15	40	II 2 411.066	35	70	I 2 472.909	1000	....
II 2 338.005	15	35	II + 2 413.309	60	100	2 473.156	5	....
2 339.58	10	....	II 2 415.063	1	50	II 2 474.765	....	60
II 2 343.492	10	50	I 2 417.490	6	....	2 474.814	40	50
II 2 343.959	5	10	II 2 417.866	10	100	2 476.029	20	....
II 2 344.280	6	20	II 2 423.094	5	....	I 2 476.654	15	25
2 345.070	20	....	II 2 424.143	25	70	I 2 479.476	8	3
II 2 348.099	5	20	2 428.20	9	....	2 479.624	7	....
II 2 348.303	5	20	II 2 430.072	15	7	I 2 479.776	200R	30
II 2 354.466	5	15	2 431.024	20	3	II 2 480.158	10	80
II 2 354.889	10	10	2 431.30	6	1	II 2 482.115	3	50
II 2 359.104	15	20	II 2 432.267	25	70	II 2 482.654	1	50
II 2 359.997	10	8	II 2 434.944	6	20	I 2 483.270‡		
II 2 360.293	10	8	2 436.344	25	....	X_1X_2	500R	5
II 2 362.019	8	15	I 2 438.181	30	4	I 2 484.187	100R	5
2 363.94	10	....	II 2 439.3	15	100	2 485.985	10	1
II 2 364.826	15	30	2 439.744	20	12	II 2 486.345	....	80
II 2 366.595	10	20	2 440.107	25	8	2 486.371	40	....
II 2 368.595	15	25	2 442.567	70	10	2 486.693	30	3
I 2 369.445	7	1	I 2 443.870	40	4	I 2 487.064	25	10
II 2 370.496	8	6	II 2 444.512	25	60	I 2 487.367	6	2
I 2 371.428	8	....	II 2 445.558	15	40	I 2 488.148	600R	100R
II 2 372.627	10	....	2 447.441	5	....	2 488.950	10	1
II + 2 373.730	6	15	I 2 447.708	70	100	I 2 489.751	200R	2
I 2 374.517	6	....	II 2 447.747	....	80	II 2 489.822	1	50
II 2 375.192	....	15	2 450.438	15	....	I 2 490.644	200R	10
II 2 376.435	8	50	2 453.474	20	3	I 2 491.155	150R	10
2 377.23	5	....	II 2 454.6	....	80	2 491.984	10	....
II 2 379.275	12	15	II 2 455.56	15	....	II 2 493.180	10	100
II 2 380.759	12	15	2 457.595	70	30	II 2 493.261	10	100
II 2 382.039P*			II 2 458.782	7	60	I 2 493.999	20	1
$LB_1N_1S_1$	40R	100R	2 459.172	6	....	I 2 494.250	10	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

IRON (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 495.863	25	35	II 2 533.627	8	50	II 2 574.368	50	150
2 496.533S_4	40	15	2 533.803	12	....	2 575.744	80	10
2 496.991	20	1	II 2 534.416	7	40	I 2 576.691	40	5
II 2 497.820	15	50	I 2 535.604	1000	....	II 2 576.865	2	70
I 2 498.894S_5	20	70	II 2 536.817	10	4	II 2 577.923	30	100
2 500.926	12	40	I 2 537.173	250	....	I 2 579.272	12	6
I 2 501.127S_6	100R	25	2 537.950	6	....	2 579.845	10	1
I 2 501.695	20	4	II 2 538.809	15	30	I 2 580.064	10	....
II 2 502.390S_7	3	60	2 538.997	10	20	2 580.30	6	1
II 2 503.325	5	50	I 2 539.357	15	....	2 580.96	5	....
2 503.655	80	....	II 2 540.666	6	30	2 582.299	50	....
II 2 503.870	8	70	I 2 540.976	100R	10	II 2 582.585	25	80
2 505.006	10	1	2 542.101	40	8	2 583.746	250	....
2 505.486	10	1	II 2 543.384	5	50	I 2 584.536	100	30
2 505.628	12	....	2 543.647	700	....	II 2 585.876	70	100
II 2 506.093	2	70	2 543.920	40	20	2 587.160	6	....
2 506.569	10	....	2 544.708	100	5	2 587.999	40	....
2 507.899	40	6	I 2 545.979	100R	30	II 2 587.948	....	50
2 508.749	20	1	2 546.874	40	1	2 591.256	20	....
II 2 509.122	1	50	2 548.08	50	....	II 2 591.543	50	100
I 2 510.834S_8	300R	50	I 2 549.613	70R	2	2 592.292	12	....
II 2 511.759	25	100	II 2 550.020	15	40	2 592.779	20	100
2 512.363	12	1	2 550.508	25	....	2 593.518	25	....
2 513.330	6	4	2 551.092	25	1	II 2 593.726	15	70
2 513.856	5	....	2 552.607	15	2	2 594.038	20	2
II 2 514.914	1	25	2 552.773	20	....	I 2 594.150	20	2
I 2 516.570	10	1	I 2 552.832	5	1	2 597.828	6	....
II 2 517.120	10	60	2 553.185	10	20	II 2 598.369	700	1000
I 2 517.659	20	12	2 553.826	9	6	2 598.854	20	....
I 2 518.101S_9	200R	50	II 2 555.066	20	20	II 2 599.396§		
2 518.824	7	....	2 555.220	10	....	S_{12}A	1000	1000
2 519.627	30	20	2 555.73	5	....	I 2 599.570	1000	....
2 520.883	80	....	2 556.30	15	1	2 599.661	6	....
2 521.814	1	60	2 556.864	20	1	2 600.10	10	....
I 2 521.917	6	....	2 558.483	10	20	2 600.202	10	....
I 2 522.848S_{10}	300R	50	II 2 560.272	10	80	2 603.565	20	3
2 523.660S_{11}	15	10	I 2 560.559	15	....	2 604.758	20	1
I 2 524.289	100R	50	I 2 561.855	15	....	2 604.867	18	....
2 525.022	20	1	I 2 562.229	15	....	2 605.040	....	80
II 2 525.387	20	60	II + 2 562.534	50	150	II 2 605.303	....	50
II 2 526.295	10	60	2 563.095	6	....	I 2 605.653	80	10
II 2 527.102	1	60	2 563.402	5	25	2 606.31	10	....
I 2 527.433	200R	50	II 2 563.474	70	125	II 2 606.504	....	80
2 528.174	6	....	I 2 564.548	15	....	I 2 606.825	200	30
2 529.1	....	70	II 2 566.912	60	150	II 2 607.087	300	400
I 2 529.133	80R	5	2 567.87	12	....	2 608.578	100	10
2 529.306	10	....	I 2 568.865	20	10	2 609.220	10	1
II 2 529.547	15	100	I 2 569.601	20	1	I 2 610.749	40	4
I 2 529.833	50R	2	I 2 569.743	10	12	II 2 611.072	20	80
2 530.692	25	70	2 570.525	10	5	II 2 611.872	500	500
2 532.53	10	....	II 2 570.841	70	100	I 2 612.771	50	10

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

IRON (*Continued*)

	Wavelength	Arc	Spark		Wavelength	Arc	Spark		Wavelength	Arc	Spar
	2 613.19	15	....		2 658.93	10	2		2 701.911	20	5
	2 613.24	10	2		2 659.24	8	2		2 702.453	15	10
II	2 613.823	400	400	I	2 660.402	40	15		2 702.55	7	3
I	2 614.490	40	5	I	2 661.196	10	7	II	2 703.989	30	400
	2 615.422	25	10		2 661.312	12	10	II	2 704.582	5	10
	2 616.44	5	3	I	2 662.056	70	40		2 706.015	60	40
II	2 617.616	300	400		2 662.315	25	10	I	2 706.581	150	150
I	2 618.017	150	60		2 663.78	10	3	II	2 707.132	....	70
I	2 618.706	70	25		2 664.040	15	5		2 707.451	20	6
II	2 619.076	5	150	II	2 664.664	20	300		2 708.570	80	50
II	2 620.407	70	40	I	2 666.405	70	10	II	2 709.056	3	100
II	2 620.695	3	80	II	2 666.635	5	80		2 709.993	40	10
II	2 621.668	200	400	I	2 666.818	80	15	I	2 710.547	80	35
I	2 623.366	25	10	I	2 666.970	30	10		2 711.463	12	3
I	2 623.532	100	80	I	2 667.919	50	20	I	2 711.654	100	50
	2 624.14	10	1		2 669.496	50	25	II	2 711.845	4	100
	2 624.37	5	....		2 670.80	10	4	II	2 712.388	2	100
	2 625.490	1	60	I	2 673.213	30	15		2 714.062	20	3
II	2 625.666	300	60		2 674.18	6	3	II	2 714.412	200	400
II	2 626.500	3	80		2 675.283	30	15	I	2 714.868	40	15
	2 627.24	8	....		2 678.05	20	10		2 715.125	5	2
II +	2 628.292	400	400	I +	2 679.062	200	200	I	2 715.323	12	5
I	2 629.587	60	150		2 680.16	20	8	I	2 715.470	100	....
II	2 630.066	10	100	I	2 680.454	70	35	II	2 716.218	20	150
II	2 631.051N$_2$	200	125		2 681.589	50	25		2 716.258	5	....
II	2 631.323	150	60		2 682.214	30	15		2 717.367	15	5
II	2 631.609	10	50		2 683.949	15	8		2 717.790	50	25
I	2 632.236	100	60		2 684.071	30	15	I	2 718.435	80	60
I	2 632.598	80	40	II	2 684.751	3	400	I	2 719.025	500R	300R
	2 632.99	10	....		2 684.857	8	....		2 719.423	20	12
	2 633.2	....	80		2 686.748	50	6		2 720.199	35	25
	2 633.64	5	1	I	2 689.212	150	150		2 720.52	8	5
I	2 635.808	300	200		2 689.423	5	3	I	2 720.905	700R	....
I	2 636.482	50	20	I	2 689.829	40	40	II	2 722.040	20	70
II	2 637.644	2	200		2 689.88	10	....		2 722.737	....	80
II	2 639.6	1	100	I	2 690.071	30	30	I	2 723.577	300	200
I	2 641.649	100	60		2 691.49	5	1		2 724.68	10	2
I	2 644.000	150	150	I	2 692.254	20	4	II	2 724.885	15	25
I	2 645.427	50	10	II	2 692.597	....	300	I	2 724.959	25	15
	2 646.32	5	....	I	2 692.655	20	....	I	2 725.29	8	4
I	2 647.557	100	70	II	2 692.836	15	20		2 725.33	8	4
	2 648.43	7	2		2 694.538	100	35	I	2 725.606	15	5
	2 648.54	6	2		2 695.039	30	20		2 726.054	100	80
II	2 649.464	....	70		2 695.534	40	30		2 726.240	25	12
II	2 650.5	....	150		2 695.662	20	12	I	2 727.384	1	40
I	2 651.706	60	60		2 695.996	80	50	II	2 727.539	150	150
	2 655.13	7	3		2 696.284	90	50		2 728.021	100	40
	2 656.149	70	40	I	2 697.021	50	25		2 728.825	50	15
I	2 656.796	50	25	II	2 697.462	3	50	I	2 728.972	15	5
II	2 658.251	....	80		2 698.165	35	6		2 730.03	8	1
	2 658.47	20	2	I	2 699.107	100	60	II	2 730.738	80	150

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

IRON (*Continued*)

	Wavelength	Arc	Spark		Wavelength	Arc	Spark		Wavelength	Arc	Spark
I	2 730.984	70	15	I	2 756.334	300	100		2 786.780	15	7
II	2 732.448	8	20	II	2 756.512	10	7	I	2 787.935	25	15
I	2 733.584	300	200	II	2 757.025	10	30	I	2 788.105	150	150
I	2 734.004	40	25	I	2 757.320	100	60	I	2 789.483	60	30
I	2 734.273	40	25		2 757.865	25	10		2 789.802	50	25
I	2 734.619	20	8	I	2 759.817	100	60		2 791 462	40	20
	2 734.888	5	....		2 760.897	15	8		2 791.792	60	40
I	2 735.475	125	100	I	2 761.785	200	....		2 792.402	50	25
I	2 735.614	20	10	II	2 761.813	50	200	II	2 793.888	8	150
	2 736.78	10	2	I	2 762.032	100	60		2 794.16	10	....
I	2 737.314	300R	150		2 762.68	50	1	I	2 794.704	50	30
	2 737.642	10	....	I	2 762.778	25	10	I	2 795.007	50	35
	2 737.834	25	10	I	2 763.108	100	70	I	2 795.544	90	60
I	2 738.213	10	2		2 764.330	70	40		2 795 85.	15	10
II	2 739.546N_3				2 766.662	15	6	I	2 796.871	15	3
	A_2	200	300	I	2 766.912	90	40	I	2 797.775	150	80
	2 741.11	10	3	II	2 767.503	10	400		2 799.153	50	10
II	2 741.397	....	70	I	2 767.523	300	....	II	2 799.286	1	100
I	2 742.017	35	15		2 768.112	35	8		2 800.28	6	2
I	2 742.256	25	25		2 768.439	25	5		2 800.464	50	10
I	2 742.408	50	50	II	2 768.934	40	100		2 803.12	35	15
II	2 743.196	80	150		2 769.302	90	10	I	2 803.172	15	....
	2 743.565	50	15	I	2 769.671	60	20		2 803.620	50	20
I	2 744.072	150	8	II	2 770.508	....	50	I	2 804.521	300	200
I	2 744.527	70	50		2 770.701	20	7		2 804.865	20	15
	2 745.082	10	1	II	2 771.184	....	50	II	2 805.791	....	50
	2 745.82	8	....		2 771.89	12	6		2 806.070	15	5
II	2 746.483	150	300	I	2 772.109	300	300	I	2 806.984	200	200
II	2 746.982	200	300		2 772.33	50	10	I	2 807.245	15	8
I	2 747.557	30	5		2 772.511	30	20		2 808.320	100	40
I	2 747.609	150	2		2 772.827	15	4		2 808.62	6	2
	2 747.972	50	100		2 773.236	90	40	II	2 809.806	1	100
II	2 749.184	40	40		2 773.90	10	5		2 810.265	40	15
II	2 749.324‖	30	30	II	2 774.691	....	50		2 812.049	15	10
II	2 749.484	15	20	I	2 774.734	80	10	I+	2 813.288	400	400
I	2 750.144	300	100		2 776.399	100	30	II	2 813.613	5	60
I	2 750.722	15	....		2 778.071	30	10		2 815.016	15	8
	2 750.878	60	20	I+	2 778.221	100	80	I	2 815.507	40	25
II	2 751.123	....	70		2 778.59	6	1		2 816.66	5	4
	2 751.37	15	....		2 778.845	70	40	I	2 817.508	100	60
	2 751.811	15	5	II	2 779.299	25	300		2 819.294	10	....
	2 753.102	25	....		2 780.54	10	2	I	2 820.809	20	15
II	2 753.287	25	150		2 780.700	30	15		2 821.01	5	3
I	2 753.692	70	25		2 780.890	10	3	I	2 823.276	200	300
I	2 754.037	90	35		2 781.01	8	2		2 825.560	150	150
	2 754.426	70	20	I	2 781.835	90	60	I	2 825.689	70	60
	2 754.95	25	....		2 782.05	12	6	I	2 826.00	6	....
	2 755.18	15	....	II	2 783.69	10	400		2 826.50	10	8
II	2 755.737¶				2 784.011	12	3		2 827.60	15	12
	LS_{13}	300	100		2 784.346	15	6	I	2 827.895	70	50
I	2 756.264	300	100		2 786.19	8	2		2 828.634	....	80

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

IRON (*Continued*)

	Wavelength	Arc	Spark		Wavelength	Arc	Spark		Wavelength	Arc	Spar
	2 828.813	100	60	I+	2 874.172	300	200		2 920.99	12	7
	2 830.964	10	....		2 874.882	60	20	II	2 922.024	....	50
II	2 831.562	1	500	I	2 875.304	125	50	I	2 922.38	10	4
I	2 832.436	300	200	II	2 875.346	....	70		2 922.620	50	25
	2 833.40	10	8	II	2 876.01	15	....		2 923.290	50	35
	2 834.18	5	3	II	2 876.802	....	100		2 923.439	30	12
	2 835.459	100	100	I	2 877.301	200	125		2 923.852S_{15}	100	70
I	2 835.955	15	10		2 879.43	7	2		2 925.363	70	50
	2 836.322	8	5	I	2 880.582	15	5		2 925.791	15	6
I	2 838.120	150	150	II	2 880.756S_{14}	15	50	I	2 925.900	15	10
I	2 840.423	125	20	II	2 883.702	....	300	II	2 926.587S_{16}	150	400
II	2 840.647	....	70		2 883.735	30	....		2 927.552	20	12
	2 840.932	7	3		2 885.350	7	2	I	2 928.105	10	4
	2 842.93	5	2	II	2 885.928	....	70	I	2 928.753	5	....
	2 843.24	6	2	I	2 886.318	50	15	I	2 929.008	150	100
I	2 843.632	125	100		2 887.154	6	2		2 929.121	10	10
I	2 843.979	300	300		2 887.807	80	60	I	2 929.624	50	10
	2 845.544	125	7	II	2 888.093	....	80		2 931.43	10	3
I	2 845.595	125	7		2 889.88	20	15		2 931.81	10	6
I	2 845.714	8	3		2 889.992	15	8		2 931.98	5	3
I	2 846.825	20	12		2 891.71	15	10	I	2 934.37	7	3
II	2 848.046	....	70		2 891.906	25	10	II	2 936.024	5	10
I	2 848.718	60	30		2 892.483	100	40		2 936.449	5	5
II	2 849.606	....	50	I	2 893.764	15	8	I	2 936.905	700R	500R
	2 851.50	5	2	I	2 893.884	25	20		2 937.811	300	150
I+	2 851.798	200	150		2 894.505	150	150	I	2 939.080	80	20
	2 852.13	150	80	II	2 894.778	....	80		2 940.591	200	80
I	2 852.958	6	2	I	2 895.035	125	70	I+	2 941.343	600	300
I	2 853.688	15	7	II	2 895.215	....	80		2 942.63	10	5
	2 853.774	15	7	II	2 897.3	....	200		2 943.57	12	6
II	2 855.670	2	200		2 898.355	100	30	II	2 944.398S_{17}	70	600
	2 857.807	12	2		2 898.86	7	4		2 945.055	100	30
	2 857.996	12	2		2 899.415	125	100		2 945.70	10	5
II	2 858.343	3	200	I	2 901.385	100	80		2 947.363	30	20
I	2 858.897	100	30		2 901.915	125	40	II	2 947.658	10	100
I	2 862.498	100	50		2 904.163	15	8	I	2 947.876	600R	200
I	2 863.435	100	80		2 905.38	7	4		2 948.433	80	70
I	2 863.864	125	100		2 906.421	60	25	I	2 948.726	10	7
II	2 864.973	....	50	I	2 907.520	100	80	I	2 948.95	10	4
I	2 866.629	125	80		2 908.859	80	40		2 949.70	10	5
	2 867.314	60	30		2 909.503	70	35		2 950.243	700	300
	2 867.563	60	30		2 910.92	10	4		2 951.56	10	4
II	2 867.648	80	100R	I+	2 912.158	150	150		2 953.486	100	50
I	2 867.880	5	2		2 914.20	10	5	II	2 953.778	50	80
	2 868.214	15	8	I	2 914.306	50	25	I	2 953.940	400R	150
II	2 868.455	80	40		2 918.027	125	100		2 954.655	100	70
I	2 869.308	300	70		2 918.357	40	25	I	2 956.70	25	8
	2 869.83	10	5		2 918.824	15	8	I	2 957.365	300	300
I	2 872.336	150	50		2 919.21	15	10		2 959.34	60	25
II	2 873.401	....	300		2 919.847	80	35	II	2 959.599	....	60
	2 873.528	15	1	I	2 920.690	150	80		2 959.682	150	10

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

IRON (*Continued*)

	Wavelength	Arc	Spark		Wavelength	Arc	Spark		Wavelength	Arc	Spark
	2 959.992	150	80		3 009.092	80	60	II	3 065.315	....	60
	2 960.299	60	30	I	3 009.570	500	400		3 066.483	60	40
	2 960.555	10	5		3 011.482	125	125	I	3 067.120	6	6
	2 960.66	6	3		3 012.450	50	30	I	3 067.244	300	300
II	2 965.037	4	50	I	3 014.175	70	35		3 067.944	15	10
I	2 965.255	400	150		3 015.9129	70	50	I	3 068.176	150	150
	2 965.811	25	15	I	3 016.185	200	150		3 072.05	6	3
I	2 966.900	1000R	600R	I	3 017.632	150	150		3 073.983	40	25
	2 968.481	30	20	I	3 018.982	150	150		3 074.151	40	25
I	2 969.362	80	80	I	3 020.489	300R	300R		3 074.438	40	25
I	2 969.477	60	60	I	3 020.640**			I+	3 075.721	400	400
I	2 970.105	400	200		X_3	1000R	600R		3 077.643	60	25
II	2 970.513	30	100	I	3 021.073S_{19}	700R	300R	II	3 077.168	1	300
	2 971.76	5	2	I	3 024.033	300	200		3 078.018	100	80
I	2 972.279	100	40		3 025.282	50	30	I	3 078.434	80	50
I	2 973.134	500R	400R		3 025.638	100	100		3 079.985	30	20
I	2 973.237	500R	400R	I	3 025.842	400R	300R		3 080.112	30	15
	2 974.778	10	6	I	3 026.461	200	200	I	3 083.742	500	500
	2 976.131	100	60	I	3 029.233	80	60		3 090.209	30	15
I	2 976.55	15	10	+	3 030.149	300	300	I	3 091.578	300	200
	2 978.05	8	3		3 030.61	5	3		3 092.778	50	30
II	2 979.352	20	100		3 031.215	150	150		3 093.357	70	40
	2 980.539	100	70	I	3 031.639	200	200	I	3 093.806	50	40
I	2 981.446	300	200		3 033.101	40	20		3 093.883	40	30
I	2 981.854	100	50	I	3 034.538	70	40	I	3 094.900	30	15
II	2 982.062	....	90		3 035.74	100	60		3 095.269	10	6
II	2 982.232	5	10	I	3 037.388	700R	400R		3 096.836	30	20
I	2 983.572	1000R	400R	I	3 037.935	800R	100		3 097.815	20	10
I	2 984.830	200R	400		3 039.316	20	15	I	3 098.192	70	60
II	2 985.550	80	300	I	3 040.428	400	400		3 098.588	5	5
I	2 986.460	100	60		3 040.96	8	4	I	3 099.897	60	60
	2 986.653	15	....	I	3 041.639	80	80	I	3 099.971	40	40
I+	2 987.292	300	200	I	3 041.737	100	80	I	3 100.304	100	100
I	2 988.474	60	30		3 042.022	125	100	I	3 100.666	100	100
	2 990.392	150	100	I	3 042.665	300	200		3 102.872	30	20
	2 991.637	100	80		3 045.078	150	100	II	3 105.168	....	60
I	2 994.429	1000R	600R		3 045.594	10	7		3 107.978	20	10
	2 996.391	90	50	I	3 047.605	800R	500R		3 110.188	6	6
II	2 997.301	....	60		3 048.455	100	8		3 110.281	40	30
	2 999.20	5	3		3 049.36	25	8		3 110.841	20	10
I	2 999.512	500	300		3 053.070	100	80		3 111.821	10	6
I	3 000.452	100	80	I	3 053.44	80	50		3 112.081	30	20
I	3 000.951	800R	300R	I	3 055.263	200	150		3 113.592	25	10
II	3 002.649	20	150		3 055.71	10	6	II	3 114.293	....	80
I	3 003.031	200	100		3 056.25	8	4	I	3 116.250	5	4
	3 004.123	18	10	I	3 057.446	400	400	II	3 116.590	....	150
I	3 004.630	5	3	I	3 059.086	600R	400	I	3 116.633	150	....
	3 005.306	70	40	I	3 060.988	50	35		3 117.640	20	10
I	3 007.145	100	80		3 061.824	5	3		3 119.494	100	80
I	3 007.281	80	60	II	3 062.233	2	400		3 120.231	5	2
I	3 008.139	600R	400R		3 063.933	40	30		3 120.434	100	80

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

IRON (*Continued*)

	Wavelength	Arc	Spark		Wavelength	Arc	Spark		Wavelength	Arc	Spar
	3 120.874	80	50	I	3 157.887	100	100		3 187.680	6	2
	3 121.773	7	5	I	3 157.98	10	6	I	3 188.571	150	100
	3 122.301	70	20		3 158.400	6	3	I	3 188.821	150	100
	3 123.346	10	4		3 159.023	7	3		3 190.016	30	10
	3 123.951	5	5		3 160.200	70	50	I	3 190.651	50	25
	3 124.889	15	7		3 160.344	40	20		3 190.816	40	20
I+	3 125.654	400	300	I	3 160.658	150	125		3 191.112	20	8
	3 126.173	150	70		3 160.917	5	4	I	3 191.659	200	150
	3 126.758	6	3	I	3 161.371	80	60		3 192.408	12	6
	3 128.285	5	4	I	3 161.949	200	150	I	3 192.802	150	8
	3 128.896	10	5	I	3 162.335	70	50	II	3 192.926	5	....
	3 129.105	15	8	II	3 162.800	1	100	I	3 193.228	100	70
I	3.129.330	100	60		3 163.874	40	25	I	3 193.303	20	15
II	3 130.278	5	4	I	3 164.299	20	10	I	3 194.423	100	70
	3 132.514	70	40	I	3 165.006	100	60		3 194.597	60	20
	3 132.680	5	3	I	3 165.861	100	80		3 195.231	6	3
	3 133.226	5	4		3 166.249	5	3	II	3 196.076	10	150
I	3 134.111	200	125		3 166.438	100	80		3 196.129	100	....
II	3 135.364	1	100	II	3 167.859	2	100	I	3 196.930	500	300
	3 135.453	10	3		3 167.922	100	30	I	3 196.997	150	....
I	3 135.861	7	4		3 168.151	10	3		3 197.517	10	8
	3 136.499	60	40		3 168.857	30	15		3 198.266	8	6
	3 138.518	10	5	II	3 170.346	10	50	I	3 199.525	300	200
I	3 139.658	15	8	I	3 171.353	100	80	I	3 200.475	150	150
	3 139.908	70	40	I	3 171.663	30	10	I	3 200.784	25	15
	3 140.391	100	80	I	3 172.067	100	100		3 202.560	40	20
I	3 142.453	125	100		3 173.412	20	10	I	3 205.400	300	200
	3 142.883	80	70		3 173.614	20	20	I	3 207.089	80	50
	3 143.245	60	30		3 173.687	20	20		3 208.475	100	80
	3 143.9896	200	150		3 174.96	5	4		3 209.297	200	125
I	3 144.495	150	100	I+	3 175.447	200	200	I	3 210.236	150	100
II	3 144.758	....	50		3 175.989	12	5	II	3 210.451	5	50
	3 145.057	40	25	I	3 176.363	20	10	I	3 210.834	150	100
I	3 146.471	5	2	II	3 177.535	5	300		3 211.487	80	40
	3 147.290	20	10	I	3 178.015	300	150	I	3 211.683	80	50
	3 147.605	10	5		3 178.546	10	6		3 211.881	10	10
	3 147.793	40	15		3 178.967	30	15	I	3 211.992	70	50
	3 148.414	100	40	II	3 180.164	10	15	II	3 213.314	50	300
	3 150.304	60	30	I	3 180.226	300	300	I	3 214.040	400	200
	3 151.351	300	150	I	3 180.755	100	100	I	3 214.399	100	50
I	3 151.869	40	15		3 181.520	80	70		3 215.416	10	4
I	3 153.206	100	80		3 181.855	15	15	I	3 215.940	300	150
	3 153.367	15	15		3 181.908	15	15	I	3 217.380	200	125
	3 153.748	40	15		3 182.061	80	80	I	3 219.581	200	125
II	3 154.206	....	400		3 182.975	125	70	I	3 222.069	200	100
	3 154.504	20	5	II	3 183.108	7	50	I+	3 225.8	300	150
	3 155.299	50	35		3 183.573	5	3	I	3 226.7	8	3
	3 155.794	5	1	I	3 184.622	60	40	I	3 227.063	30	10
	3 156.274	125	100	I	3 184.896	200	150	II	3 227.747	200	300
I	3 157.040	150	100	II	3 186.741	20	300	I	3 228.254	100	80
	3 157.451	10	5	II	3 187.293	....	60		3 228.597	5	2

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

IRON (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 228.905	80	40	3 269.959	5	3	+ 3 323.727	150	150
I 3 229.123	80	50	I+ 3 271.002	300	300	3 324.366	5	3
3 229.593	10	5	3 271.486	15	7	I 3 324.537	100	80
3 229.873	10	10	I 3 271.683	25	15	I 3 325.462	100	80
3 229.994	20	20	3 272.595	6	3	I 3 327.491	15	7
I 3 230.211	100	80	3 274.453	80	60	3 328.867	150	100
I 3 230.967	300	200	I 3 276.468	100	50	3 329.054	8	3
3 233.054	100	60	II 3 277.346	40	200	3 329.532	35	6
I 3 233.971	300	150	3 278.734	100	60	3 330.313	5	2
I 3 234.611	200	125	3 279.739	7	3	I 3 231.612	125	70
3 235.59	5	2	3 280.261	150	150	3 331.776	40	10
I 3 236.223	300	200	II 3 281.300	15	100	I 3 334.2	150	100
II 3 237.819	1	100	3 282.892	80	80	3 335.8	125	100
I 3 239.436	400	300	3 283.543	7	3	3 336.3	40	30
3 243.109	50	20	I 3 284.588	200	125	3 337.7	125	100
3 243.403	70	20	II 3 285.415	60	40	3 338.636	70	25
II 3 243.723	....	60	I 3 286.022	30	15	I 3 339.195	80	50
I 3 244.190	300	200	3 286.446	5	3	I 3 339.582	10	5
I 3 245.984	200	150	I 3 286.755	500	400	I 3 340.566	125	100
3 246.482	40	25	3 287.113	5	3	3 341.905	100	80
I 3 246.962	100	70	3 288.654	15	6	I 3 342.216	40	40
3 247.213	10	10	3 288.967	30	15	3 342.292	20	20
I 3 247.278	20	10	3 289.436	10	4	I 3 346.936	30	15
I 3 248.206	200	150	3 290.719	15	7	I 3 347.927	150	100
3 249.192	70	35	I 3 290.989	125	80	I 3 350.285	8	4
3 250.394	20	6	3 292.023	150	125	I 3 351.521	70	60
I 3 250.627	60	40	I 3 292.590	300	150	3 351.745	80	60
I 3 251.235	300	150	3 293.142	10	5	I 3 352.930	5	3
3 252.437	90	40	3 296.467	12	6	I 3 352.267	10	5
3 252.926	80	50	I 3 298.133	200	150	3 354.064	40	40
3 253.602	100	80	3 299.075	5	2	3 355.229	100	100
3 253.949	20	8	3 301.222	15	7	I 3 356.402	35	8
3 254.363	200	150	II 3 303.471	5	5	3 356.693	15	1
3 254.734	15	6	3 303.567	70	10	3 358.909	5	....
II 3 255.890	20	100	3 305.135	5	2	I 3 359.491	15	3
3 256.698	20	7	I 3 305.971	400	300	3 359.815	10	2
I 3 257.240	25	12	I 3 306.354	200	150	I 3 360.928	7	1
I 3 257.594	100	100	3 307.012	5	4	3 361.952	6	1
II 3 258.773	....	150	3 307.232	80	60	3 362.279	6	....
II 3 259.048	1	200	3 310.342	100	80	3 363.811	6	1
I 3 259.994	150	100	3 310.489	50	40	3 364.278	7	1
3 260.261	20	15	3 312.226	5	2	3 366.789	50	25
3 261.333	25	7	I 3 314.072	5	2	I 3 366.867	50	15
3 262.013	30	15	3 314.447	15	6	3 367.161	10	3
3 262.280	50	25	3 314.742	200	200	3 368.168	5	1
I 3 263.369	30	15	I 3 317.121	100	80	3 369.549	300	200
I 3 264.513	80	60	3 319.249	70	50	+°3 370.786	300	200
I 3 265.048	200	150	I 3 320.650	20	10	I 3 372.080	40	7
I 3 265.619	300	300	3 320.779	30	12	3 376.50	5	1
I 3 268.236	125	100	3 322.477	150	100	3 377.20	5	5
3 269.235	20	6	II 3 323.068	....	100	3 378.685	150	80

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

IRON (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I+°3 379.022	80	50	3 433.045	50	1	I 3 504.859	10	5
°3 380.111	200	25	3 437.051	80	15	3 505.061	10	10
I 3 381.337	5	2	3 437.952	15	7	I °3 506.498	50	30
I 3 382.409	50	10	3 438.306	10	3	3 508.485	40	20
I 3 383.698	100	70	3 439.872	15	7	I 3 508.535	20	10
I 3 383.989	200	100	I 3 440.610S_{20}	500	300	I 3 509.868	15	4
3 387.411	35	8	I 3 440.991	300	200	I 3 510.446	15	8
3 387.630	5	....	I 3 442.361	50	15	3 512.227	5	1
3 386.626	5	1	I 3 442.677	30	5	I 3 513.065	10	2
I 3 389.749	15	4	I 3 443.878	400	200	I+°3 513.820	400	300
3 392.014	20	6	I+°3 445.151	300	150	3 514.626	7	2
I 3 392.313	125	80	3 445.771	10	3	3 516.420	40	15
I °3 392.657	300	200	I °3 447.281	100	60	3 516.558	30	4
I 3 393.381	6	3	I °3 450.330	150	80	3 518.685	7	1
3 393.917	6	1	I 3 451.619	15	4	3 520.855	10	4
I 3 394.087	7	2	I 3 451.918	100	60	I °3 521.264	300	200
I 3 394.589	150	80	I 3 452.277	150	8	I 3 521.841	50	20
I °3 396.978	125	25	3 453.023	30	15	I 3 522.276	50	30
I 3 397.642	10	2	3 457.086	5	....	I 3 522.893	10	3
I 3 399.234	5	....	°3 458.309	60	25	3 523.312	10	4
I+ 3 399.336	200	200	3 459.429	10	3	3 524.071	50	40
I °3 401.521	150	90	I 3 459.918	80	50	I 3 524.241	60	50
°3 402.262	150	150	I 3 462.361	10	3	I 3 526.042	80	50
I 3 404.304	25	25	I 3 463.302	7	1	I 3 526.169	50	25
I 3 404.359	100	50	I °3 465.863	500	400	3 526.383	20	10
3 406.442	30	10	I 3 466.500	30	70	I 3 526.464	20	10
I 3 406.805	100	60	I 3 466.895	10	4	I 3 526.676	80	50
I °3 407.461	400	400	II 3 468.679	10	20	I 3 527.797	100	80
3 409.20	40	4	I 3 468.848	30	12	°3 529.820	125	80
3 410.176	30	20	3 469.011	18	1	I 3 530.389	50	25
I 3 410.900	10	2	I 3 469.834	35	10	3 532.576	5	2
3 411.356	80	30	I 3 471.270	40	15	3 533.010	50	75
3 412.640	8	....	I 3 471.34	40	15	I 3 533.202	50	50
I °3 413.135	400	300	3 473.309	10	2	I 3 534.914	5	2
I 3 415.534	60	20	3 474.440	10	6	I 3 535.186	40	10
3 417.164	5	....	I 3 475.454	400	300	I 3 536.557	300	200
3 417.262	6	....	I 3 475.651	6	6	I 3 537.493	25	8
I °3 417.843	150	100	I 3 476.344	5	2	I 3 537.731	25	15
I °3 418.512	150	100	I °3 476.704	300	200	I 3 537.897	50	25
3 419.699	7	2	3 477.856	20	4	I 3 540.118	100	60
3 422.493	40	10	3 478.629	20	6	I 3 540.713	10	4
I 3 422.660	100	50	I 3 483.010	50	10	I °3 541.086	200	200
I °3 424.288	200	150	I+°3 485.34S_{21}	100	50	I 3 542.078	150	100
3 425.015	70	40	°3 489.670	20	15	I 3 542.235	5	1
I 3 426.32	50	2	I 3 490.575	400	300	3 543.392	10	2
I 3 426.388	80	20	II 3 493.474	40	80	3 543 674	60	30
I 3 426.636	80	60	I °3 495.289	100	60	3 544.633	50	6
I °3 427.121	50	50	3 495.896	6	1	I °3 545.640	90	70
I 3 428.197	50	50	I °3 497.108	200	100	I 3 547 198	25	8
3 428.753	5	2	I °3 497.843	200	200	I 3 548.024	10	7
3 431.814	50	20	3 500.567	50	20	3 548.089	9	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

IRON (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 3 549.872	15	5	3 591.487	6	....	3 627.790	8	1
3 552.118	10	6	3 592.209	6	....	I 3 628.094	10	3
I 3 552.831	80	50	I 3 592.692	12	2	I °3 630.349	40	15
3 553.741	100	100	I 3 593.329	7	2	I 3 631.096	25	10
I 3 554.120	50	20	I ■3 594.636	125	100	I °3 631.464	500	300
I 3 554.929	400	300	I 3 595.308	20	7	°3 632.040	50	50
I+°3 556.883	300	150	3 596.198	15	5	3 632.556	30	25
3 557.298	15	....	3 597.061	40	10	I 3 632.979	12	8
I+°3 558.518	400	300	3 598.721	6	2	3 633.078	10	3
3 559.509	50	25	3 599.146	10	5	3 633.833	7	3
3 560.697	50	15	3 599.623	40	30	3 634.334	15	5
I 3 564.116	15	2	3 599.974	5	....	3 634.687	20	2
3 564.530	30	15	I 3 602.085	20	5	I 3 635.196	12	2
I °3 565.381	400	300	3 602.466	10	5	I 3 636.186	40	10
I 3 565.588	10	4	I 3 602.529	50	30	3 636.234	15	10
I 3 567.038	50	15	I ■3 603.208	150	80	3 636.650	5	3
I 3 567.383	10	2	I 3 603.823	20	12	I 3 636.995	20	10
I 3 568.423	20	4	3 604.27	5	....	I 3 637.250	12	5
3 568.822	15	7	3 604.380	10	1	I 3 637.866	20	7
I 3 568.979	50	35	I 3 605.211	12	2	I °3 638.298	100	80
I 3 570.097	300	300	I °3 605.458	300	150	I+°3 640.390	300	200
3 570.258	50	15	I+°3 606.682	200	150	3 642.81	20	....
I 3 571.227	40	6	I 3 608.150	15	25	3 643.11	30	5
I 3 571.996	100	80	I °3 608.861	500	400	3 643.626	20	8
3 573.400	50	20	I 3 610.162	100	90	I 3 643.713	6	4
3 573.836	20	15	I 3 610.702	10	3	3 643.815	7	1
3 573.888	40	30	3 612.074	80	50	3 644.798	20	6
I 3 575.118	15	5	I 3 612.945	20	4	I 3 645.081	20	8
I 3 575.250	10	5	3 613.452	10	2	3 645.222	9	....
3 575.375	40	30	3 614.116	10	3	I 3 645.494	15	7
I 3 575.980	80	25	3 614.561	15	6	°3 645.825	80	60
°3 576.760	80	40	3 614.715	6	1	I 3 647.426	20	15
I 3 578.380	40	5	3 615.201	10	1	I °3 647.844	500	400
I °3 581.195††	1000R	600R	I 3 615.665	10	2	I 3 649.304	60	25
°3 582.201	30	30	I 3 616.572	30	7	I 3 649.508	100	100
3 583.341	50	15	3 617.318	25	15	I 3 650.032	70	30
3 583.692	6	1	°3 617.788	125	80	I 3 650.280	70	50
I °3 584.663	100	60	3 618.389	8	4	I 3 651.10	10	3
°3 584.960	30	25	I °3 618.769	400	400	I ■3 651.469	300	200
I °3 585.320	150	100	3 619.390	12	1	3 652.73	6	....
I 3 585.707	125	80	3 620.471	15	2	I 3 653.763	25	10
°3 586.114	80	80	I °3 621.463	125	100	I 3 655.467	25	25
I 3 586.986	200	150	3 621.715	6	5	3 655.675	15	2
3 587.240	5	2	I 3 622.005	125	100	3 656.227	15	5
I 3 587.422	10	5	I °3 623.186	100	80	I 3 657.139	20	7
I 3 587.758	50	25	I 3 623.446	15	5	I 3 657.904	20	4
I 3 588.616	35	10	I 3 623.772	35	7	I 3 658.552	5	1
I 3 588.914	10	4	3 624.307	10	2	I ■3 659.521	125	50
I °3 589.107	70	30	3 624.814	12	2	I 3 660.335	5	1
I °3 589.456	50	30	I °3 625.148	70	35	I 3 661.374	10	1
I 3 591.345	12	3	3 627.04	10	3	3 662.849	30	5

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

IRON (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spar
3 663.267	8	3	3 703.823	15	10	I 3 751.820	5	2
I 3 663.458	25	7	I °3 704.463	125	100	I 3 752.420	12	4
I 3 664.540	35	8	I °3 705.567	700	500	I+°3 753.614	150	100
3 664.694	12	3	I °3 707.049	150	100	3 756.071	15	8
I 3 666.249	20	7	I 3 707.824	80	50	°3 756.941	80	60
3 667.262	80	25	I 3 707.925	80	60	3 757.455	15	10
I 3 667.999	60	10	I 3 708.602	5	2	I °3 758.235	700	700
I 3 668.214	15	4	I 3 709.249	600	400	I °3 760.052	150	100
3 668.893	5	1	3 709.533	6	6	3 760.534	100	70
I 3 669.157	50	30	I °3 711.225	80	50	I 3 761.408	20	8
I °3 669.523	200	150	3 711.410	50	25	I 3 762.209	7	3
I 3 670.028	100	....	3 712.964	5	1	I °3 763.790	500	400
3 670.071	200	200	I °3 715.915	80	50	°3 765.542	200	150
I 2 670.812	20	6	I 3 716.448	150	100	I °3 767.194	500	400
3 673.087	10	4	I 3 718.408	80	50	I 3 768.029	15	8
3 674.415	12	5	I °3 719.935P			I 3 769.990	80	30
3 674.768	40	25	$S_{22}C$‖‖‖	1000R	700	I 3 770.303	35	12
I+°3 676.314	200	100	3 721.271	7	4	I 3 773.699	40	10
I 3 676.879	10	2	I 3 721.510	10	4	I °3 774.827	100	40
3 677.308	40	30	3 721.611	6	4	°3 776.459	125	70
+°3 677.630	80	60	3 721.921	15	10	3 777.062	12	7
I 3 678.864	100	50	I °3 722.564	500	400	I 3 777.447	20	10
I 3 678.98	5	1	I+°3 724.380	200	150	I 3 778.320	8	4
I °3 679.915	500	300	3 725.490	15	8	3 778.513	60	25
3 680.798	12	7	I 3 726.925	100	70	I 3 778.701	10	4
3 681.227	6	2	I 3 727.095	30	10	I 3 779.446	100	70
I 3 682.209	400	300	I 3 727.621	200	150	I °3 781.190	40	12
I 3 683.058	200	100	I 3 728.667	18	10	3 781.935	12	5
I °3 684.112	300	200	3 730.390	70	40	3 782.130	8	2
I 3 686.003	150	125	3 730.947	50	30	I 3 782.456	10	2
3 686.258	10	4	3 731.378	40	20	3 785.713	10	4
I 3 687.101	15	7	°3 732.399	200	150	°3 785.951	125	80
I °3 687.458	400	300	I °3 733.319	400	300	I 3 786.176	100	60
I 3 687.662	15	15	I °3 734.867‡‡	1000R	600	I °3 786.679	125	50
3 688.476	40	8	I 3 735.330	30	20	I °3 787.883	500	300
I 3 689.463	200	150	I °3 737.133p	1000R	600	3 789.177	80	50
3 689.897	5	1	°3 738.308	100	100	I °3 790.095	200	100
3 690.459	15	6	I 3 739.129	10	5	I 3 790.760	10	3
°3 690.730	80	60	I 3 739.312	7	2	I 3 791.507	7	2
3 692.652	5	1	3 739.531	80	35	3 791.73	5	2
3 693.032	15	7	3 740.061	8	4	I 3 792.160	40	20
I 3 694.010	400	300	3 740.251	70	35	I 3 792.833	10	3
°3 695.054	200	150	I °3 742.624	50	25	I 3 793.360	5	2
I 3 697.432	100	60	I 3 743.363	200	150	I 3 793.484	10	5
3 698.605	40	20	I 3 744.105	40	20	I 3 793.877	25	10
I 3 699.141	15	3	I °3 745.564p	500	500	°3 794.340	80	50
I 3 701 090	300	200	I °3 745.903P	150	100	I °3 795.004	500	400
°3 702.031	50	30	3 746.929	40	25	°3 797.517	300	200
I 3 702.495	20	7	I °3 748.264	500	200	I °3 798.513	400	300
I 3 703.555	30	25	I 3 748.969	35	20	I °3 799.549	400	300
I 3 703.696	12	7	I 3 749.487	1000R	700	3 801.682	50	25

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

IRON (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 801.807	7	3	I °3 856.373	500	300	I 3 914.281	15	3
I 3 801.985	25	5	I 3 859.216	100	100	3 916.733	100	80
3 802.285	25	10	I °3 859.913F			I °3 917.185	150	70
I 3 804.013	40	10	S_{23}	1000R	600	I 3 918.320	20	10
I+°3 805.345	400	300	3 861.342	80	50	3 918.420	15	10
I °3 806.699	200	150	I 3 863.742	60	30	I 3 918.646	60	40
I °3 807.537	150	100	I+°3 865.526	600	400	I 3 919.070	15	7
I 3 808.730	100	70	I °3 867.219	150	100	I °3 920.260	500	300
3 809.574	15	5	I 3 867.923	30	8	I 3 922.914	600	400
3 810.761	70	25	I 3 869.564	100	80	I 3 925.200	15	3
I 3 811.895	15	10	I °3 871.750	100	60	I 3 925.646	80	50
I 3 812.964	400	300	I °3 872.504	300	300	I °3 925.947	50	30
3 813.632	35	15	I °3 873.763	125	80	I °3 927.922	500	300
3 813.890	50	25	I °3 876.045	40	15	I 3 928.083	15	15
I °3 814.523	80	40	I °3 878.021	400	300	3 929.124	10	5
3 814.785	10	5	I °3 878.575	300R	300	3 929.212	15	8
I °3 815.842	700	700	I 3 878.676	30	....	I °3 930.299	600	400
I 3 816.340	25	20	3 878.736	10	10	I 3 931.123	35	15
3 817.650	50	15	°3 883.289	70	40	I 3 932.630	80	40
I 3 820.429	800	600	°3 884.362	80	35	3 932.921	8	4
°3 821.178	100	100	I 3 885.514	100	60	I 3 933.605	200	200
I 3 821.838	50	30	I °3 886.284S_{24}	600	400	I 3 935.306	40	8
I 3 824.078	5	3	3 888.823	40	15	I+°3 935.815	100	8
3 824.302	7	7	3 890.237	15	....	I °3 937.332	80	35
I °3 824.444	150	100	3 890.844	60	30	I+°3 940.882	150	80
I °3 825.884	500	400	3 891.929	100	70	I 3 941.280	60	10
3 826.846	6	2	3 892.894	5	2	I °3 942.443	100	70
I 3 827.825	200	200	I 3 893.318	5	4	I 3 943.348	40	8
3 829.459	15	8	I 3 893.394	100	8	I 3 944.896	15	8
3 829.77	8	2	I 3 893.915	10	4	3 945.126	30	10
I 3 830.761	10	3	3 894.012	8	8	I 3 947.005	50	20
I 3 830.860	12	4	I °3 895.658	400	300	I 3 947.532	70	20
I °3 833.310	100	60	I 3 897.447	10	5	I 3 948.107	125	50
I °3 834.225	400	400	3 897.895	100	60	°3 948.779	150	100
3 836.333	100	60	I 3 898.013	80	50	I 3 949.957	150	100
I 3 837.142	25	6	3 899.01	6	....	3 951.168	150	125
°3 839.259	100	75	I 3 899.038	20	8	I °3 952.606	80	50
I °3 840.439	400	300	I °3 899.709	500	300	I 3 952.702	8	1
I °3 841.051	500	400	I 3 900.519	60	3	I 3 953.155	80	40
3 842.885	6	2	I °3 902.948	500	400	3 953.861	8	2
+°3 843.259	125	100	I °3 903.900	100	80	I 3 955.354	25	5
3 844.283	10	1	I+°3 906.482	30	200	3 955.960	10	5
I 3 845.174	100	60	3 906.751	10	10	°3 956.460	100	100
3 845.704	10	6	3 907.470	15	6	I °3 956.681	150	150
3 846.415	50	75	+°3 907.937	100	60	3 957.030	50	15
I °3 846.803	125	100	I 3 909.669	20	5	3 960.285	30	6
3 848.298	5	2	I 3 909.835	40	12	I 3 961.145	25	7
I °3 849 969	500	400	I °3 910.844	30	10	I 3 962.353	7	1
+°3 850.820	200	75	3 911.011	6	2	I 3 963.109	125	50
I 3 852.575	150	100	3 912.05	5	5	I 3 964.520	80	25
I 3 853.463	7	3	I 3 913.635	100	25	I 3 965.513	10	3

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

IRON (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spar
I °3 966.066	100	70	I 4 018.275	50	7	I °4 085.008	80	30
I 3 966.629	80	40	I+°4 021.870	200	100	I 4 085.324	100	70
°3 967.423	125	100	I 4 024.104	8	2	I 4 087.103	50	5
I 3 967.969	60	15	I 4 024.739	120	30	4 088.577	7	2
I °3 969.261	600	400	I 4 029.636	80	25	I 4 089.222	10	2
3 969.633	5	5	I 4 030.194	20	4	I 4 091.562	8	3
3 970.263	5	2	I 4 030.492	120	60	4 092.287	6	1
3 970.394	50	30	°4 031.965	80	50	I+°4 095.976	80	40
I °3 971.329	200	125	I 4 032.630	80	15	I °4 098.187	100	40
3 973.654	40	10	4 040.644	20	7	4 100.166	10	1
I 3 974.398	10	1	4 041.285	5	2	I °4 100.743	80	30
I 3 974.764	8	....	I 4 043.905	25	7	I 4 101.274	40	10
3 975.842	8	1	I °4 044.611	70	35	I 4 101.679	5	2
3 976.614	8	35	I °4 045.815§§	400	300	I 4 104.128	100	25
I 3 976.864	30	10	I 4 049.331	10	2	I 4 106.265	6	1
I+°3 977.744	300	150	4 049.87	30	3	I 4 106.439	10	2
I 3 978.464	6	1	4 050.688	5	....	I °4 107.492	120	100
3 979.641	6	....	4 051.908	10	2	I 4 109.072	12	2
I °3 981.774	150	100	4 053.273	6	2	I °4 109.808	120	100
I °3 983.962	200	125	I 4 054.833	25	5	I 4 112 347	6	1
3 985.388	125	40	I 4 054.883	25	5	4 112.966	70	10
I °3 986.172	125	8	I 4 055.039	40	10	I °4 114.449	80	50
3 989.010	15	1	I 4 057.346	20	3	4 114.957	10	2
3 989.860	30	5	4 058.229	80	25	I 4 117.863	6	1
3 990.379	70	25	I 4 058.760	40	10	+°4 118.549	200	100
I 3 994.121	25	10	4 059.721	15	8	°4 120.211	80	35
3 995.200	10	....	I °4 062.444	120	100	I °4 121.806	100	40
I 3 995.989	60	20	I 4 063.284	10	10	I °4 122.510	70	30
3 996.972	40	20	I 4 063.597‖‖			4 123.745	80	20
I °3 997.396	300	150	S_{25}	400	300	4 125.621	80	30
I 3 998.055	150	100	I 4 065.392	15	6	I 4 125.883	25	15
I 4 000.266	8	1	4 066.590	40	20	I 4 126.190	80	60
4 000.452	35	10	I °4 066.979	100	80	I 4 126.88	8	1
I 4 001.667	80	50	I °4 067.275	80	70	I °4 127.612	100	80
4 003.767	30	80	I °4 067.982	150	100	4 127.803	25	15
4 004.843	10	7	I 4 070.779	50	20	4 129.22	5	1
I °4 005.246	250	200	I 4 071.740	300	200	I 4 130.04	20	3
4 006.315	60	35	II 4 073.450.	8	8	I °4 132.060	300	200
4 006.631	20	15	I 4 073.775	80	20	I 4 133.862	50	7
I 4 006.761	7	2	I+°4 074.791	80	40	I 4 134.425	10	3
I 4 007.273	80	50	4 075.937	5	5	I+°4 134.681	150	100
4 008.873	5	1	I+°4 076.637	80	50	°4 137.004	100	80
I °4 009.717	120	100	4 076.803	8	1	I 4 139.923	40	30
I 4 011.412	5	1	I 4 078.358	80	40	I 4 141.867	15	5
I 4 013.647	8	1	I 4 079.845	80	40	I °4 143.420	200	100
I 4 013.795	80	40	I 4 080.221	60	10	I 4 143.871	400	250
4 013.824	200	....	4 080.887	5	1	I 4 146.070	15	3
°4 014.534	200	100	I 4 082.117	10	2	I+°4 147.673	200	100
I 4 016.429	15	4	I 4 083.554	10	2	I 4 149.370	100	35
I 4 017.093	5	....	I 4 083.780	15	2	I 4 150.264	50	2
I 4 017.153	80	50	I 4 084.499	120	80	I 4 152.170	70	5

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

IRON (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 4 153.910	120	100	I 4 217.555	200	100	I 4 290.868	20	2
I 4 154.503	100	80	I+°4 219.364	250	200	I 4 291.466	125	20
I 4 154.812	100	8	4 220.348	80	40	I 4 292.290	15	....
I+°4 156.803	100	80	I 4 222.221	200	200	I °4 294.128S_{31}	700	400
I 4 157.791	150	80	I 4 224.176	200	80	I °4 298.040	100	400
I 4 158.789	100	25	I 4 224.517	60	15	I 4 299.241	500	400
I 4 161.080	10	....	I 4 225.465	80	20	I 4 302.192	50	10
4 161.492	15	....	I 4 225.957	80	30	II 4 303.168	12	15
I 4 163.676	12	1	I °4 226.430	80	25	I °4 305.455	100	50
4 165.420	12	2	I 4 227.432	300	250	I 4 307.906***	1000R	800R
4 167.862	8	2	I 4 229.761	20	2	4 309.039	40	20
4 167.960	10	2	I 4 232.732	10	1	I 4 309.380	125	70
4 168.946	10	1	II 4 233.168	100	100	I+°4 315.087	500	300
I °4 170.906	80	40	I+°4 233.612	250	150	4 321.800	20	4
4 171.700	8	2	I 4 235.942	300	200	I 4 325.765†††	1000	700
4 172.127	80	50	4 237.167	5	2	I 4 326.760	10	4
I 4 172.750	60	10	I 4 238.039	80	15	°4 327.098	100	50
I 4 173.323	25	5	I 4 238.821	200	100	4 330.155	10	2
II 4 173.475	8	8	4 239.733	30	10	4 330.959	5	....
I 4 173.927	50	5	I 4 239.849	40	15	I °4 337.049	400	150
I 4 174.917	100	25	4 240.370	30	5	4 343.257	20	3
I+°4 175.640	100	80	4 243.368	10	3	I 4 343.634	20	5
I 4 176.572	100	25	I+°4 245.260	80	40	°4 346.556	50	10
I °4 177.596	100	25	4 246.090	80	30	I °4 351.552	30	5
II 4 178.868	10	10	I 4 247.433S_{26}	200	100	II 4 351.762	30	30
I °4 181.757	200	150	I 4 248.226	150	40	I+°4 352.737	300	150
I 4 182.386	80	30	I 4 250.130	250	150	I °4 358.505	70	20
I+°4 184.895	100	80	I °4 250.790S_{27}	400	250	I °4 367.582	100	50
I 4 187.044	250	200	4 255.499	5	2	I 4 367.906	60	70
I 4 187.801	200	150	I 4 258.324	60	4	I °4 369.774	200	100
I+°4 191.436	200	100	I 4 258.614	12	2	I 4 373.566	50	3
I 4 191.680	20	6	I 4 258.958	8	2	I+°4 375.932	500	200
I 4 195.337	170	100	I 4 260.003	15	5	I 4 376.783	7	1
I 4 195.623	25	3	I 4 260.134	7	3	4 382.773	10	10
I 4 196.214	100	50	I 4 260.479S_{28}	400	300	I 4 383.547‡‡‡		
I 4 198.312	250	150	I 4 264.215	35	4	S_{32}	1000	800
I 4 198.643	10	2	I 4 264.74	12	2	I 4 384.699	5	2
I 4 199.099	300	200	I 4 266.968	70	30	I °4 387.897	150	35
I 4 200.927	80	20	°4 267.830	125	60	I 4 388.411	125	50
I °4 202.031	400	300	4 268.758	30	10	I 4 389.247	35	2
4 202.758	10	4	I 4 271.161	400	300	I °4 390.954	100	35
I 4 203.572	10	1	I °4 271.764¶¶			I 4 395.286	80	....
I+°4 203.987	200	120	S_{29}	1000	700	4 400.351	20	1
I 4 205.546	50	6	I 4 276.678	10	1	I 4 401.300	60	15
I 4 206.702	125	25	I 4 279.480	5	1	I 4 401.450	7	2
I 4 207.131	80	40	I+°4 282.406S_{30}	600	300	I °4 404.752§§§	1000	700
4 208.615	100	50	4 285.445	125	50	I °4 407.716	100	50
I 4 210.352	300	200	I 4 286.992	10	1	I 4 408.419	125	60
°4 213.650	100	60	I 4 288.154	50	6	4 410.714	20	....
I 4 215.425	60	15	I 4 288.965	5	1	I °4 415.125	600	400
I °4 216.186	200	100	4 290.381	35	5			

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

IRON (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spa
4 419.543	8	1	I 4 531.652	8	1	I 4 728.560	20	
I °4 422.570	300	125	+°4 547.851	200	100	I 4 729.699	25	2
I+°4 427.312	500	200	II 4 549.470	100	100	II 4 731.492	5	
I 4 430.207	10	1	4 550.795	50	....	I+°4 733.596	15	
I °4 430.618	200	8	4 552.594	10	1	4 735.848	10	
4 432.573	5	1	I 4 556.125	150	35	I+°4 736.780	125	5
I 4 433.221	150	20	I 4 560.096	20	....	I+°4 741.533	12	
I °4 435.152	70	3	4 565.329	6	....	I °4 745.806	8	
I 4 436.930	15	2	I 4 565.667	8	1	4 747.480	30	2
I 4 438.353	10	1	4 566.520	5	1	4 768.340	6	...
I 4 439.885	6	1	I 4 568.777	10	1	I °4 772.817	10	4
I °4 442.343	400	200	I 4 574.722	12	1	I °4 786.810	150	...
I °4 443.197	200	100	I 4 581.522	60	2	I °4 788.753	40	...
I 4 446.842	10	10	II 4 583.848	150	150	I+°4 789.654	100	...
I °4 447.722	200	100	4 587.136	12	2	I 4 791.248	200	20
I °4 454.383	200	80	I 4 592.655	200	50	4 800.656	15	...
I 4 455.035	20	1	4 595.365	15	2	4 821.047	200	20
I 4 458.107	30	1	I 4 596.062	10	2	I 4 832.730	5	...
I °4 459.121	400	200	I 4 598.135	50	4	I 4 855.686	8	1
I 4 461.224	5	1	I 4 602.010	20	2	I+°4 859.748	150	40
I °4 461.654S_{33}	300	125	I+°4 602.944	300	100	I 4 871.325	200	30
I 4 464.776	35	3	I 4 607.654	50	5	I 4 872.146	100	30
I+°4 466.554	500	300	I 4 611.289	200	25	I+°4 878.218	80	4
4 466.940	7	....	I 4 613.219	30	2	I 4 886.346	5	...
I 4 469.380	200	100	I 4 618.765	10	1	I 4 889.009	2	150
4 472.721	10	1	I °4 619.298	100	8	I 4 890.769	100	15
I °4 476.022	500	300	I 4 625.055	100	12	I 4 891.498	70	15
4 476.079	40	8	II 4 629.328	7	8	I+°4 903.317	500	2
I 4 479.622	15	2	I °4 630.128	10	2	I 4 905.182	10	...
I 4 480.144	10	2	I °4 632.918	70	4	I 4 907.745	25	...
I 4 482.172	150	70	I 4 637.518	100	10	I 4 909.390	50	...
I 4 482.258	150	70	I °4 638.018	80	10	I 4 910.026	100	...
I 4 482.752	20	2	I 4 643.475	35	2	I 4 910.570	15	...
I 4 484.225	125	40	I °4 647.437	125	40	I 4 911.800	10	...
I 4 485.680	50	2	I °4 654.503	20	3	I+°4 918.999	300	50
I 4 488.132	7	....	I 4 654.624	10	2	I 4 920.505	500	125
I 4 489.741	100	12	I °4 667.459	150	20	4 923.720	5	100
I °4 490.087	40	10	I 4 668.140	125	10	II 4 923.916	30	50
I 4 490.765	40	1	I 4 669.184	15	2	I+°4 924.776	100	...
I °4 494.568	400	150	I °4 673.172	20	2	4 927.447	50	6
II 4 508.285	40	30	I 4 678.852	150	100	4 927.875	20	...
II 4 515.345	10	10	I 4 680.305	9	....	I 4 930.331	25	...
I °4 517.530	30	3	I 4 683.566	6	....	4 933.348	50	30
II 4 520.236	40	30	I 4 690.144	7	....	4 933.627	2	70
II 4 522.634	60	50	I+°4 691.414	80	10	I 4 934.023	40	...
I 4 525.146	100	50	I+°4 707.281	100	12	I 4 938.183	100	...
4 526.419	10	1	4 708.960	50	50	I 4 938.817	300	1
I °4 528.619	600	200	I 4 709.098	20	2	I 4 939.244	10	...
I 4 529.563	6	....	I+°4 710.286	20	2	I+°4 939.690	150	...
4 529.676	10	2	4 714.074	50	50	I 4 946.400	5	40
I+°4 531.152	125	....	I 4 727.407	10	....	4 946.639	1	50

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

IRON (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 4 952.646	5	....	I 5 079.753	100	....	5 217.924	6	....
I 4 957.307	100	20	I+°5 083.342	200	....	I 5 225.531	60	....
I 4 957.609	300	150	5 086.765	2	100	I 5 226.875	200	15
4 962.564	10	....	I 5 090.789	40	....	I °5 227.192	400	60
I+°4 966.096	300	1	I 5 096.995	35	....	5 228.413	15	6
4 969.927	50	....	I °5 098.710	200	....	I 5 229.867	200	15
4 970.496	20	....	I 5 102.200	80	....	I+°5 232.940	800	150
I 4 973.108	100	....	5 106.441	25	....	I 5 235.390	35	....
I 4 978.606	80	....	I 5 107.452	100	....	5 236.197	6	....
4 982.507	200	....	I+°5 110.414	300	....	°5 242.495	125	5
I 4 983.258	100	....	I+▫5 123.723	200	....	I 5 243.789	20	....
I 4 983.855	200	....	I 5 125.130	100	....	I 5 247.063	50	10
I 4 985.260	100	....	I 5 126.213	5	....	I 5 250.211	30	....
I 4 985.559	100	....	I ▫5 127.363	100	....	I+°5 250.650	150	....
I 4 988.963	100	....	I 5 131.474	125	....	5 251.971	12	....
4 990.462	5	....	I 5 133.680	200	1	I 5 253.480	70	....
I 4 991.277	80	....	II 5 136.795	3	100	I 5 254.961	50	....
I+°4 994.133	200	....	I 5 137.388	200	....	I 5 263.330	300	....
4 995.627	3	60	I 5 139.260	125	....	5 263.874	7	....
4 997.801	20	300	I 5 139.480	200	40	I 5 266.03	6	....
I+°5 001.871	300	40	I 5 141.747	100	100	I+°5 266.579	500	40
I 5 002.809	20	....	I 5 142.540	100	....	I °5 269.541	800	200
5 004.99	7	....	I 5 142.940	125	....	I+°5 270.360	400	80
5 005.727	200	....	I 5 145.098	10	....	I 5 273.170	80	4
I 5 006.133	300	5	I 5 148.052	20	....	I 5 273.378	50	4
I 5 007.288	25	....	I 5 148.258	35	....	5 280.380	15	....
5 010.852	50	....	I+°5 150.843	150	....	I 5 281.799	300	20
5 011.31	5	....	I ▫5 151.914	70	....	I 5 283.626	400	40
I+°5 012.071	300	....	5 159.053	35	....	II 5 284.092	....	70
I 5 014.959	500	....	I 5 162.288	300	....	5 287.922	100	20
II 5 018.440	80	50	5 164.614	70	....	5 288.530	30	....
I 5 022.250	150	....	I 5 165.424	50	....	I 5 290.850	15	....
5 023.476	10	300	I ▫5 166.296	125	....	5 293.973	8	....
I 5 027.136	60	....	I+°5 167.491	700	150	5 298.780	12	....
5 027.212	60	....	I ▫5 168.901	80	....	I+°5 302.314	300	....
5 028.137	100	....	II 5 169.027	2	200	II 5 303.419	25	25
II 5 030.784	1	125	I °5 171.599	300	60	I °5 307.365	125	....
I 5 039.261	100	2	5 180.058	10	....	I 5 315.07	5	....
I °5 041.081	125	....	I 5 191.467	400	35	5 320.048	6	....
I+°5 041.759	300	....	I+°5 192.357	400	50	5 321.113	8	....
I 5 044.221	25	....	I 5 194.948	200	15	I 5 322.054	30	....
I 5 048.454	50	....	I 5 195.478	100	....	I+°5 324.182	400	70
I+°5 049.825	400	1	5 196.098	25	....	5 326.157	6	....
I °5 051.636	200	....	I °5 198.714	80	....	I 5 328.051	400	100
I 5 065.016	25	....	5 198.837	10	....	I+°5 328.534	150	35
5 065.201	15	....	I+°5 202.339	300	10	5 329.999	15	....
I 5 068.786	400	200	I 5 204.583	125	....	I 5 332.901	50	....
5 070.957	1	70	I 5 208.601	200	8	I 5 339.938	200	30
I 5 074.760	80	....	I 5 215.185	200	5	I+°5 341.026	200	15
I 5 078.993	20	....	I+▫5 216.278	300	10	I 5 343.470	12	....
I 5 079.236	100	....	I 5 217.398	150	3	I 5 353.389	60	2

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

IRON (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spar
5 362.751	6	....	I 5 522.461	8	....	5 791.041	6	2
5 364.883	200	10	I 5 525.553	40	2	I 5 806.730	10	5
5 365.405	40	....	I 5 534.66	20	....	5 816.376	15	10
5 367.460	200	15	5 535.411	50	....	5 825.691	6	....
5 369.957	150	20	5 538.57	50	....	5 830.587	5	....
I+°5 371.493	700	....	5 539.28	30	....	5 834.779	6	....
I 5 373.712	15	....	5 543.183	25	....	5 842.484	6	....
I 5 376.849	5	....	I 5 544.928	10	....	5 845.868	8	....
5 378.858	5	....	I 5 546.490	40	....	5 856.081	8	3
5 379.577	35	....	I 5 553.585	6	....	5 859.197	6	2
5 383.371	400	40	I 5 554.887	100	....	I 5 859.608	15	12
I 5 389.461	60	....	I 5 560.223	5	....	I 5 862.363	35	35
I 5 391.475	25	....	I 5 562.709	15	....	5 869.756	10	....
I 5 393.182	150	10	I 5 563.604	100	5	I 5 873.219	8	2
I °5 397.131	400	50	I 5 565.702	70	....	5 875.372	15	....
I 5 398.285	70	....	I 5 567.399	30	....	5 878.002	5	....
I 5 400.503	125	....	I+°5 569.625	300	15	5 879.782	8	....
5 403.819	30	....	I 5 572.849	300	25	I 5 879.994	6	....
I 5 404.148	300	35	I 5 573.105	8	....	I 5 883.848	15	10
I+°5 405.778	400	70	I 5 576.106	150	....	5 902.527	6	....
I 5 409.132	10	....	5 584.764	25	2	5 905.683	12	8
I 5 410.909	200	10	I+°5 586.763	400	50	5 906.015	6	....
I 5 415.207	500	20	5 587.576	6	....	5 908.252	8	....
5 424.076	400	20	5 594.659	10	....	5 908.409	5	....
I °5 429.699	500	40	I 5 598.289	20	....	5 910.597	5	....
I+°5 434.527	300	35	I 5 602.779	8	8	5 912.834	10	....
I 5 436.595	5	....	I 5 602.956	45	35	I 5 914.162	50	25
I 5 445.037	150	....	I+°5 615.652	400	300	I 5 916.258	25	4
I 5 446.920	300	35	I 5 618.640	10	8	5 918.05	5	....
5 449.779	10	....	I 5 624.549	150	125	5 927.806	10	....
I 5 455.433	50	....	5 630.35	5	2	I 5 930.186	30	10
I+°5 455.613	300	30	5 633.962	20	10	I 5 934.680	15	12
I 5 462.969	50	....	I 5 638.272	40	20	I 5 940.968	6	....
I 5 463.283	100	....	I 5 641.464	15	8	I 5 952.740	8	....
5 464.279	6	....	I 5 655.498	10	5	I 5 956.708	12	....
I 5 466.407	25	....	I 5 658.537	30	2	5 969.554	5	....
I 5 473.920	100	....	I+°5 658.826	100	80	5 975.358	10	10
5 474.917	100	....	I 5 662.525	50	50	I 5 983.705	35	12
5 476.295	12	....	I 5 667.525	5	3	I 5 984.804	50	20
I 5 476.578	80	....	I 5 686.377	100	1	I 5 987.055	25	12
I 5 480.873	10	....	5 686.522	10	8	5 999.950	10	....
I 5 481.252	5	....	I 5 701.556	50	25	I 6 003.034	30	15
I 5 481.459	5	....	I 5 705.978	15	10	I 6 007.966	10	10
I 5 483.116	15	....	I 5 709.379	100	....	I 6 008 576	18	10
I 5 487.138	50	5	I 5 717.840	10	2	6 013 505	100	....
I 5 487.775	10	....	I 5 731.770	10	3	I 6 016 655	100	....
I+°5 497.519	150	5	I 5 752.056	8	2	I 6 020 179	8	10
I °5 501.469	150	....	I 5 753.136	40	20	I 6 021 829	300	....
I 5 505.885	9	....	I+ 5 763.011	80	35	I+ 6 024.063	20	2
I 5 506.782	150	10	I 5 775 091	12	2	I 6 056 001	10	10
5 514.631	50	10	5 789 649	8	....	I+°6 065 487	50	30

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

IRON (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 6 078.481	8	6	I °6 518.374	10	7	+7 132.989	15	10
I 6 102.182	15	20	I °6 546.245	150	50	I 7 142.522	12	8
I 6 103.185	8	....	I 6 569.224	50	25	I 7 145.317	15	10
I °6 127.915	8	....	I °6 575.022	12	15	I 7 151.495	8	....
I+°6 136.620	100	....	I+°6 592.919	150	80	I 7 155.64	10	....
I+°6 137.696	100	....	I 6 593.878	30	18	I+ 7 164.469	200	100
I 6 141.759	10	....	I 6 597.607	10	....	I 7 175.937	8	....
II 6 147.849	5	6	I °6 609.116	25	12	I 7 176.886	10	....
I 6 151.632	8	....	I 6 633.772	60	25	I+ 7 181.93	8	....
°6 157.734	15	....	I °6 663.446	70	25	I+ 7 187.341	500	300
I 6 170.502	15	....	I+°6 677.993	250	150	I 7 189.17	7	8
I °6 173.339	18	....	I+ 6 703.575	7	5	7 194.92	8	....
I 6 180.216	6	....	I 6 705.117	12	12	I+ 7 207.406	300	300
I+°6 191.562	100	20	I 6 715.410	5	....	I 7 212.48	8	....
I °6 200.327	15	....	I 6 717.556	5	....	+ 7 219.686	12	18
I 6 213.443	20	....	6 726.78	15	....	I 7 221.23	10	8
I ⊡6 219.289	40	5	I 6 733.171	5	....	I+ 7 223.668	20	....
6 227.241	5	....	I+°6 750.157	50	18	I 7 228.69	8	....
I+°6 230.728	60	50	I+ 6 752.734	9	12	I+ 7 239.885	25	20
I 6 232.657	5	5	I 6 804.020	7	....	I 7 244.86	18	....
I 6 246.335	20	20	I 6 808.859	8	7	7 254.649	10	8
I °6 252.561	60	25	I 6 810.25	15	18	I 7 261.54	18	10
I °6 254.261	10	....	6 820.38	10	7	7 282.39	5	....
I 6 256.369	8	....	I+ 6 828.610	18	25	+ 7 284.853	15	15
I+°6 265.140	12	5	I+ 6 841.349	50	50	I+ 7 288.760	30	20
I 6 290.977	5	....	I 6 842.668	8	5	I+ 7 293.068	100	50
I °6 297.797	10	15	I+ 6 843.671	30	35	7 294.98	5	....
I 6 301.517	50	50	I+ 6 855.179	60	80	7 300.47	8	....
I 6 302.511	15	15	6 857.25	5	5	I 7 306.61	25	12
I 6 315.310	5	....	I 6 858.164	15	15	+ 7 307.957	30	....
I+°6 318.022	40	25	I 6 862.481	7	....	I+ 7 311.101	60	25
I °6 322.691	8	8	I+ 6 885.77	10	8	II+ 7 320.70	25	18
I+°6 335.335	50	20	I+ 6 916.702	35	5	I 7 333.62	8	....
I 6 336.839	60	35	I+ 6 933.632	5	....	I 7 351.160	8	7
I °6 344.153	5	2	I+ 6 945.208	60	20	I 7 351.56	18	7
I 6 355.039	15	8	I+ 6 951.261	10	....	I 7 363.95	8	....
I 6 358.690	8	6	I+ 6 978.855	60	12	7 376.434	8	....
°6 380.747	25	8	I+ 6 988.530	8	....	I 7 382.92	6	....
I+°6 393.605	100	80	I+ 6 999.902	25	....	+ 7 386.402	40	25
I 6 400.018	200	150	I 7 008.014	9	....	I+ 7 389.425	100	80
I 6 408.029	50	30	I 7 016.436	100	25	+ 7 401.689	10	....
I 6 411.664	100	80	I+ 7 023.003	40	30	I+ 7 411.178	100	....
I 6 419.977	18	15	7 024.084	5	....	+ 7 418.674	10	....
I °6 421.355	60	40	I 7 024.649	15	8	I 7 430.87	5	....
I+°6 430.851	100	80	I+ 7 038.251	7	20	I 7 440.98	18	....
I °6 462.729	20	7	I+ 7 068.415	40	30	I+ 7 443.022	8	....
I 6 469.214	8	5	I 7 083.396	5	....	I+ 7 445.776	150	....
I °6 475.625	8	8	I+ 7 090.404	50	25	I 7 476.30	12	....
I 6 481.874	12	80	I 7 095.425	8	....	I+ 7 491.678	20	....
I ⊡6 494.985	400	150	I+ 7 107.461	5	8	I+ 7 495.088	200	....
6 496.456	10	....	I+ 7 130.942	100	80	I+ 7 507.28	40	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

IRON (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spar
I+ 7 511.045	20	1	I+ 7 664.302	15	....	I 7 912.866	5	....
I+ 7 531.171	80	....	I+ 7 710.390	10	....	I+ 7 937.166	40	1
I+ 7 583.796	5	....	II 7 711.73	25	15	I 7 941.09	5	....
I+ 7 586.044	10	....	I+ 7 748.281	25	....	I+ 7 945.878	30	2
I+ 7 620.538	5	....	I 7 751.13	5	....	7 994.473	6	....
I+ 7 653.76	80	....	I+ 7 780.586	25	....	I+ 7 998.972	35	1
I+ 7 661.223	10	....	I+ 7 832.224	30	1			

Control lines:		Interfering lines:
*As	2370.8	*Pt Te Tl
Co	2378.6	
†Ni	2416.1	†Ag Mo Pb Cr Ir Ni Cb Mo Sb
‡Sn	2421.7	‡Bi Cu Hg Mo
§Sb	2528.5	§Pb Sb
‖AuC	3122.8	‖Au Cd Cr Pt
Cr	2750.7	
¶Cr	2750.7	¶Ag Ge V W
**Bi	2989.0	**Cr Hg Mo V W
Cr	2605.3	
††Mo	3624.5	††Au Ba Mo Pd
‡‡Ca	3179.3	‡‡Ca Co Cu Mo
Ti	3752.9	
§§Co	4092.4	§§Co Cr Hg K Ni Pt
K	4044.2	
Mn	4055.6	
‖‖Co	4086.3	‖‖As Au Co Cu Ni Pb
Cu	4651.2	
¶¶Cr	4254.3	¶¶Be Bi Co Cr Pt Ti
Ti	4337.9	
***Ca	4318.6	***Ba Bi Ca Cd Co Ni Pt Sr Ti
Ti	4533.2	
†††Mo	4288.7	†††Ba Be Co Cr Na Ni Pt
V	4323.8	
‡‡‡Cr	4371.3	‡‡‡Al Bi Cr Mn Mo Pt Sc
Mo	4385.9	
Pb	4245.2	
§§§Sc	4374.5	§§§Al Ba Co Cr Mo Te Ti V W
V	4111.8	
		‖‖‖Mo Th Ti Cu Ba Ce W

Control lines:	
B$_1$Co	2378.6
S$_1$Cu	2356.5
	2406.7
S$_2$Cu	2406.7
	2473.5
S$_3$Cu	2406.7
S$_4$Si	2516.1
S$_5$Si	2516.1
S$_6$Si	2516.1
S$_7$Si	2516.1
S$_8$Si	2516.1

Control lines:	
S$_9$Si	2516.1
S$_{10}$Si	2528.5
S$_{11}$Si	2524.1
S$_{12}$Cu	2600.4
S$_{13}$Cu	2703.3
S$_{14}$Si	2881.6
S$_{15}$Mn	2933.1
	2939.3
S$_{16}$Si	2881.6
S$_{17}$Mn	2949.2

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

IRON (*Continued*)

Control lines:

S_{19}Cu	3036.1
	3073.8
S_{20}Cu	3454.7
S_{21}Cu	3478.2
S_{22}Sr	4607.3
S_{23}Sr	4607.3
S_{24}Sr	4607.3
S_{25}Sr	4607.3
S_{26}Mn	4254.3
S_{27}Mn	4254.3
S_{28}Mn	4277.8

A_1Al	3050
A_2Al	2669
X_1Mo	2649
X_2Mo	3158
X_3Mo	3208

Control lines:

S_{29}Mn	4254.3
Sr	4607.3
S_{30}Mn	4254.3
	4289.7
S_{31}Mn	4289.7
S_{32}Sr	4607.3
S_{33}Sr	4607.3
N_1Sn	2380.7
N_2Sn	2523.9
	2455.8
N_3Sn	2779.3

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

LANTHANUM

La

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 297.8	2	150	II 3 949.1P	1000	800	II 4 559.3	100	150
2 379.4L	....	60	II 3 988.5	1000	800	I 4 567.9	100	25
II 2 519.2	....	50	II 3 995.8A_1	600	300	I 4 570.0	80	25
II 2 610.3	10	150	I 4 015.4	100	2	II 4 574.9	300	300
II 2 808.4	10	150	II 4 023.6	50	15	II 4 580.1	80	100
II 2 855.9	3	50	II 4 025.9	50	50	II 4 605.8	100	100
II 2 885.1	5	50	II 4 031.7	400	300	II 4 613.4	100	100
II 2 893.1	6	60	I 4 037.2	50	3	II 4 619.9	150	200
II 2 950.5	3	50	II 4 042.9	400	300	II 4 655.5	150	300
II 3 104.6	200	50	II 4 050.1	60	60	II 4 662.5	150	200
II 3 142.8	150	50	I 4 060.3	80	5	II 4 663.8	100	200
3 171.7	2	1000	II 4 067.4	150	80	II 4 668.9	200R	300R
II 3 193.0	15	60	II 4 077.3P	600	400	II 4 671.8	100	150
II 3 245.1	400	300	II 4 086.7	500	500	II 4 692.5	200	300
II 3 249.4	300	80	II 4 099.5	100	100	II 4 699.6	200R	200R
II 3 265.7	300	200	II 4 123.2pL	500	500	II 4 703.3	200R	300R
II 3 303.1	400	150	II 4 141.7	200	200	II 4 712.9	100R	150
II 3 337.5	800	300	II 4 152.0	200	300	II 4 716.4	100	200
I 3 342.2	80	5	II 4 152.8	40	50	II 4 719.9	200R	300
II 3 344.6	300	200	I 4 160.3	40	50	II 4 728.4	400R	300
II 3 376.3	100	50	I 4 187.3	50	40	II 4 740.3	150	300
II 3 380.9	200	100	II 4 192.4	50	50	II 4 743.1	300R	300
II 3 452.2	50	40	II 4 196.5	200	150	II 4 748.7	100	200
II 3 453.2	50	40	II 4 204.0	200	25	I 4 766.9	100	10
II 3 512.9	50	15	II 4 217.6	200	100	II 4 804.0	150	150
3 517.1	....	25	II 4 231.0	150	50	II 4 809.0	150	150
II 3 628.8	80	40	II 4 238.4	500	300	II 4 824.1	150	150
II 3 637.1	50	40	II 4 250.0	100	50	II 4 860.9	100	100
II 3 645.4	100	60	I 4 256.9	50	....	II 4 899.9	400	200
II 3 650.2	100	60	II 4 263.6	150	150	I 4 901.9	50	....
II 3 662.1	60	40	II 4 269.5	150	150	II 4 921.0	500	400
II 3 705.8	50	80	II 4 275.6	40	500	II 4 921.8	500	400
II 3 713.5	200	60	I 4 280.3	50	30	II 4 934.8	150	100
II 3 714.9	60	40	II 4 287.0	400	300	II 4 946.5	100	50
II 3 715.5	100	50	II 4 296.0	200	200	I 4 949.8	200	....
II 3 759.1	400	150	II 4 315.9	50	3	II 4 952.1	50	40
II 3 780.7	50	50	II 4 322.5	150	150	II 4 970.4	125	100
II 3 790.8	400	300	II 4 333.7L	800	500	II 4 986.8	150	100
II 3 794.8	400	200	II 4 335.0	40	50	II 4 991.3	100	80
II 3 840.7	50	70	I 4 340.7	50	3	I 4 993.9	80	....
II 3 846.0	40	50	II 4 354.4	80	100	II 4 999.5	400	300
II 3 849.0	200	150	II 4 364.7	50	50	I 5 046.9	80	....
II 3 864.5	100	150	II 4 378.1	40	30	I 5 050.6	80	4
II 3 871.6	200	15	II 4 383.5F	10	50	I 5 056.5	80	....
II 3 886.4	400	200	II 4 429.9	200	300	I 5 106.2	100	10
II 3 916.0	400	400	II 4 522.4	200	400	II 5 114.6	150	200
II 3 921.5	400	200	II 4 525.3	100	100	II 5 123.0	150	200
II 3 929.2	400	300	II 4 526.1	100	150	I 5 145.4	100	10
II 3 936.2	100	50	II 4 558.5	100	200	II 5 157.4	40	100

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

LANTHANUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 5 158.7	50	....	I 5 744.4	80	....	I 6 456.0	100	....
I 5 177.3	150	30	I 5 761.8	60	....	I 6 485.5	50	....
II 5 183.4	300	400	I 5 769.3	70	....	II 6 498.2	25	125
II 5 188.2	50	500	I 5 789.2	125	....	II 6 527.0	125	100
II 5 204.2	50	300	I 5 791.3	200	....	I 6 543.2	125	....
I 5 211.9	300R	5	II 5 797.6	80	150	I 6 578.5	100	....
I 5 234.3	200R	8	II 5 805.8	60	120	I 6 608.3	50	....
I 5 253.5	100	5	II 5 808.3	25	60	6 611.7	100	150
II 5 259.4	40	50	II 5 880.6	30	50	I 6 616.6	125	....
I 5 271.2	100	20	I 5 930.6	150	....	I 6 650.8	100	....
II 5 290.8	60	100	I 5 930.7	100	....	I 6 661.4	70	....
II 5 302.0	300R	200	II 5 973.5	15	120	I 6 692.9	50	....
II 5 302.6	50	150	I 6 007.4	70	....	I 6 709.5	150	....
II 5 303.6	100	125	I 6 038.6	50	....	I 6 753.0	100	....
II 5 340.7	80	100	I 6 108.5	70	....	II 6 774.2	100	120
II 5 381.0	50	100	I 6 111.7	50	....	I 6 823.8	50	....
II 5 381.9	15	100	I 6 134.4	70R	....	I 6 925.2	100	....
I 5 455.1	200	1	I 6 143.0	50	....	I 6 935.0	50	....
5 501.3	200	50	I 6 166.7	100	....	II 6 958.1	25	50
I 5 503.8	100	....	I 6 249.9p	300	....	I 7 023.7	100	....
I 5 506.0	50	....	II 6 262.3	125	150	I 7 046.0	125	....
I 5 510.3	200	....	I 6 266.0	80	....	II 7 066.2	400	150
II 5 535.7	50	100	II 6 296.1	50	150	I 7 068.4	100	....
I 5 541.3	50	....	II 6 320.4	70	100	II 7 104.7	50	2
I 5 631.2	50	....	II 6 390.5	70	100	I 7 158.1	125	....
I 5 648.3	150	....	I 6 394.2	150	....	I 7 161.3	100	....
I 5 657.7	50	....	II 6 399.1	15	200	II 7 282.3	70	125
II 5 671.6	10	100	I 6 411.0	100	....	I 7 334.2	100	....
I 5 696.2	50	....	II 6 446.6	15	100	I 7 345.3	125	....
I 5 740.7	100	1	I 6 454.5	125	....			

A_1 Z_1 3991.1

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

LEAD

Pb

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 059.6	500R	....	2 613.7	50R	5	3 572.7	200	20
2 087.6	12	....	2 614.2**S_5	200R	80	I 3 639.6p§N_7C	300	50
2 088.4	30R	40	$G_1N_3X_2C$			3 671.4	....	70
2 111.7	20	8	II 2 628.3S_6	50	10	3 671.5	30	7
2 115.0	30R	8	2 650.4	100	80	I 3 683.5p‖LB_1	300	50
2 159.5	15	....	2 657.2S_4	....	....	N_8S_{11}		
I 2 170.0P	1000R	1000R	2 663.2G_2N_4C	300	40	3 739.9	150	60
2 175.6	40	....	2 802.0†G_3N_5	250R	100	3 832.8	....	50
2 187.9	50	3	2 823.2A_2X_1	150R	40	3 841.6	....	60
II 2 203.5A_1PN_1	50	5000R	G_4C			I 3 854.1	....	100
2 218.1	50	40	I 2 833.1p‡S_8N_6	500R	80R	I 3 951.9	....	50
2 237.4	50	30	G_6C			4 019.6	6	6
2 242.6	15	15	2 864.3	....	60	I 4 057.8p¶FL	2000R	300R
2 246.9	30R	100R	2 864.5	....	60	$S_{12}G_8$		
2 254.0	40	5	2 873.3S_7G_7C	100R	60	N_9X_2C		
2 332.4	60	30	II 2 948.7	....	125	4 062.1	20	20
2 388.8S_1	40	18	I 3 043.9	....	100	4 168.0	20	10
2 393.8	2500	1000	I 3 137.8	....	100	4 242.5	....	10
2 399.6	35	12	I 3 176.5	....	100	4 245.0	....	20
2 401.9	50	40	3 220.5S_{10}	50	5	5 692.3	20	....
2 411.7S_2	75	15	3 232.4	30	....	5 895.7	20	2
2 443.8	100	15	3 240.2	30	....	6 001.9	40	3
2 446.2S_3	150	15	3 262.4	20	5	6 235.4	20	....
2 476.4S_4	150	25	3 276.2	....	60	7 229.1	50	....
2 577.3N_2C	100	40	I 3 455.5	....	70			

Control lines:	Interfering lines
*Fe 2628.3	*Ag Co Fe V Sb
Sb 2670.7	
W 2613.1	
†Mg 2795.5	†Au Hg Mg Mn
Mn 2798.3	
V 2810.2	
Zn 3075.9	
‡Cr 3605.3	‡Au Fe Hg W Ce Ta
Fe 2844.0	
Pt 2929.8	
W 2848.0	
W 2947.0	
§Ca 3706.0	§Ba Co Cr Fe Hg Pt Zn Rh U Th

Control lines:	Interfering lines:
Mo 3614.3	
Mo 3158.2	
Sc 3630.8	
Ti 3653.5	
‖Fe 3709.3	‖Ag Co Fe Hg Pt
Fe 3705.6	
Mo 3695.0	
Ti 3234.5	
V 3695.9	
V 3695.3	
¶Mn 4048.8	¶Ag Co Cr Cu Fe Mo V In Mn Ti Zn Mg
Mn 4041.4	**Ir Fe Pt Sb Sn Ta Co U

Control lines:	
S_1Sn	2706.5
S_2Sn	2421.7
S_3Cu	2406.7
S_4Cu	2406.9
S_5Cu	2618.4
S_6Sn	2571.6
S_7Bi	2730.5

Control lines:	
S_{12}Cu	4062.8
G_1Sn	2594
	2637
G_2Sn	2661
G_3Sn	2851
	2765
G_4Sn	2765

Control lines:	
N_4Zn	2670.4
N_5Sn	2787.9
	2790.2
	2761.8
N_6Sn	2761.8
N_7Sn	3223.6
	3218.7

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

LEAD (*Continued*)

Control lines:
2780.5
Sn 2571.6
2706.5
S_8Cu 2858.3
2882.8
S_9Cu 2858.3
2882.8
S_{10}Bi 3024.6
3067.7
S_{11}Cu 3687.5

Control lines:
G_6Sn 2851
G_7Sn 2765
G_8Sn 3801
3656
N_1Sn 2209.3
2211.0
N_2Sn 2558.0
N_3Sn 2594.4
2637.0

Control lines:
3655.9
N_8Sn 3655 9
N_9Zn 4680.2
4629.9
Sn 4524.7
3223.6
2655.9
3218.7
B_1Ni 3619.4
A_1Zn 2103
A_2Zn 2684
X_1Mo 3158
X_2Sn 2707

LITHIUM

Li

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 425.7	30	....	I 3 718.7	30	....	I 4 602.9†C	800	....
I 2 475.3	100	5	I 3 794.7	60	....	I 4 972.0	500	....
I 2 562.5	150	15	I 3 915.0	200	....	I 6 103.6‡C	2000R	300
I 2 741.3	200	....	I 3 985.8	100	....	I 6 240.1	300	....
2 899.7	....	60	I 4 132.3	400	....	I 6 707.8P§AC	3000R	200
I 3 232.6p*C	1000R	500	I 4 273.3	200R	100			

Control lines: Interfering lines:
*Ni 3057.6 *Ag Au Co Fe Mn Ti Tl W
Sb 3267.5 Ni Fe Mo Sb Ph Ce
Ti 3361.2
Ti 3222.8 ‡Th Cb Co Ca Rh Cr
ASr 6408.5

Control lines: Interfering lines:
Ti 3529.4
†Cr 4616.1 †Al As Ba Be Co Mn Mo Ni
Fe 4482.3 P Pb
Sr 4215.5 §Mo Co W Ta

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

LUTECIUM

Lu

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 191.4	6	60	3 056.7	50	100	4 658.0	100	15
2 195.5	30	100	3 057.9	3	150	4 785.4	100	200
2 236.2	....	150	3 077.6	100	200	4 839.6	50	100
2 297.4	15	100	3 081.5	80	8	4 904.9	60	5
2 392.2	30	100	3 191.8	3	60	4 994.1	250	400
2 399.1	10	50	3 198.1	40	80	5 001.1	100	....
2 481.7	20	100	3 254.3	50	150	5 135.1	200	20
2 578.8	40	125	3 279.0	50	5	5 402.6	150	10
2 613.4	30	100	3 281.7	60	5	5 421.9	50	5
2 615.4	100	250	3 312.1	100	10	5 476.7	500	1000
2 619.3	30	100	3 359.6	150	15	5 736.6	150	15
2 657.8	50	150	3 376.5	100	10	5 775.4	50	5
2 685.1	50	3	3 397.1p	50	20R	5 983.6	30	60
2 701.7	40	150	3 472.5p	50	150	5 984.1	20	40
2 754.2	40	125	3 507.4	100	150	5 997.1	50	5
2 772.6	5	150	3 508.4	30	3	6 004.5	400	40
2 796.6	25	100	3 554.4p	50	150	6 055.0	150	10
2 821.2	2	50	3 567.8	100	7	6 159.9	50	200
2 847.5	40	125	3 624.0	20	40	6 221.9	500	1000
2 894.8p	60	200	3 636.2	25	3	6 235.4	25	100
2 900.3	50	150	3 647.8	100	5	6 242.3	40	200
2 911.4p	100	300	3 841.2	100	8	6 345.4	60	4
2 951.7	20	80	3 876.6	50	100	6 463.1	400	800
2 955.8	2	60	3 968.5	50	....	6 523.2	80	5
2 963.3	5	150	4 124.7	200	10	6 917.3	50	....
2 969.8	30	100	4 184.3	100	200	7 031.2	50	....
2 989.3	50	4	4 518.6p	300	40	7 125.8	125	....
3 020.5	....	100						

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

MAGNESIUM

Mg

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 025.8	8	....	II 2 802.7X_1A_2p†	150	300	II 3 538.9	8	....
II 2 329.6	12	....	LB_2C			I 3 829.4p	100	150
II 2 449.6	20	....	I 2 846.8	18	4	I 3 832.3p	250	200
I 2 632.9	10	4	I 2 848.4	20	....	I 3 838.3	300	200
I 2 649.0	12	....	I 2 851.7	25	....	II 3 848.2	10	10
II 2 660.8	40	6	I 2 852.1A_3P‡	300R	100R	II 3 850.4	8	5
II 2 660.8	40	6	LC			I 3 878.6	10	....
I 2 669.5	12	....	2 915.5	20	12	I 3 986.7	15	3
I 2 672.5	20	....	II 2 928.8	25	100	I 4 057.6	10	....
I 2 693.7	10	....	II 2 936.5	20	....	I 4 351.9	15	2
I 2 695.2	10	....	I 2 936.9	12	....	II 4 390.6	10	....
I 2 698.1	12	....	I 2 938.5	25	....	II 4 428.0	7	....
I 2 733.6	25	....	I 2 942.1B_3	20	2	II 4 434.0	8	....
I 2 736.5	30	3	II 2 967.9	10	....	4 481.2	....	50
2 776.7C	30	20	3 074.0	8	10	II 4 481.3	100	....
2 778.3C	25	20	I 3 091.1	80	10	I 4 571.1	20	2
2 779.8X_2X_3	40	50	I 3 093.0	125	20	II 4 739.6	5	....
A_4C			I 3 096.9	150	25	II 4 851.1	5	....
2 781.4C	20	8	II 3 104.7	15	....	I 5 167.3	100	50
2 783.0X_2X_3	15	15	II 3 104.8	15	....	I 5 172.7	200	100
A_3A_4C			I 3 229.4	25	....	I 5 183.6	500	300
II 2 790.8A_1A_4	40	80	I 3 329.9B_4	80	8	I 5 528.5	60	30
II 2 795.5A_2P*	150	300	I 3 332.2	100	25	I 5 711.1	4	....
LB_1C			I 3 336.7	125	60	II 6 347.1	10	2
II 2 798.1	30	80	II 3 535.0	8	....	II 6 545.4	10	2

Control lines:		Interfering lines:
*Mn	2794.8	*Fe Mn Sb Ag Rh Cr Ce U
W	2848.0	
†Mn	2798.3	†Au Bi Cr Cu Hg Ce Ta Co
Pb	2833.1	Pb Ti V W Zn U Mn
V	2810.2	
Zn	3075.9	
‡Cr	2849.8	‡Au Cr Fe Na Sb Ir Mo Ag
Cr	2843.3	Ce Zr V
Fe	2844.0	
Mo	2816.2	
A_1Al	2816.2	
Al	3050.1	
A_2Au	2676.9	
A_3Al	2816	
	2652	
A_4Al	2669	

Control lines:		Interfering lines:
Sn	2546.5	
W	2866.1	
B_1Cu	2961.2	
	3036.1	
Sn	3262.3	
B_2Cu	2824.4	
Zn	3075.9	
B_3Cu	3247.5	
B_4Zn	3345.0	
X_1Mo	2816	
X_2Mo	3158	
X_3Mo	3208	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

MANGANESE

Mn

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 003.8	50R	25	II 2 605.7p‡	100R	500R	2 725.9	....	50
2 092.1	30R	20	LA$_2$C			2 726.1	300	....
2 093.4	30R	18	2 610.2A$_4$	15	100	2 728.6	....	50
2 106.0	40R	....	2 616.5	....	60	2 738.9	25	....
2 109.6	40R	12	2 618.1	50	100	2 752.3	20	....
2 191.4	25	10	2 618.9	40	12	2 760.9	80	....
2 213.8	60R	10	2 619.5	125	10	2 771.4	25	....
2 230.0	....	60	2 620.0	50	12	2 776.2	80	....
2 231.7	....	70	2 622.9	200	15	2 778.6	60	....
2 269.9	2	70	2 624.0	25	60	2 780.0	25	....
2 299.0	20	40	2 624.0	25	60	2 782.7	50	....
2 305.0	40	60	2 624.8	25	12	2 790.4	20	....
2 311.0	25	....	2 625.6	....	100	2 794.8§XC	1000R	5
2 320.5	....	60	2 626.6	125	5	2 798.3‖C	800R	80
II 2 373.4	4	50	2 630.6	100	15	2 799.8	20	....
2 384.1	40	3	2 632.4	12	80	2 801.1¶C	600R	60
2 427.4	....	50	2 635.4	12	80	2 806.1	25	....
2 428.0	....	50	2 635.6	....	60	2 808.0	20	....
2 452.5	3	100	2 638.2	25	8	2 809.1	25	....
2 458.7	....	80	2 639.8	12	80	2 812.8	20	....
2 460.9	25	3	2 648.8	20	....	2 813.5	30	1
2 461.0	25	5	2 648.9	1	50	2 815.0	25	75
2 466.2	....	50	2 651.0	....	150	2 818.0	50	1
2 472.9	125	100	2 652.5	3	100	2 818.8	25	1
2 488.1	150	12	2 662.5	....	50	2 818.9	20	....
2 490.6	125	3	2 666.8	8	50	2 821.5	40	....
2 491.2	100	2	2 667.0	5	50	2 828.8	50	....
2 527.4	150	12	2 671.8	....	50	2 830.8	50	....
2 529.1	80	5	2 672.6	15	125	2 840.0	20	....
2 533.1	20	1	2 673.4	....	50	2 872.6	30	....
2 535.6	....	80	2 681.2	....	50	2 882.9	25	....
2 541.1	....	80	2 681.7	20	15	2 892.7	20	....
2 542.9	1	100	2 684.5	2	80	2 900.5	50	....
2 543.5	4	100	2 685.9	12	100	2 902.2	50	....
2 563.6	25	50	2 687.4	25	80R	2 907.2	50	....
2 572.8	200	50	2 688.2	3	100	2 908.0	20	....
2 575.5	150	1	2 692.7	150	....	2 914.6	150	....
II 2 576.1P*LC	300R	2000R	2 694.1	8	50	2 925.6	150	1
2 579.7	125	1	2 695.4	100R	50	2 928.7	25	....
2 583.0	....	50	2 698.9	5	100	2 930.2	25	....
2 584.3	150	15	2 701.7	150	40	2 933.1G$_1$	80	15
2 589.7	....	80	2 704.0	100	25	2 934.0	25	....
2 589.7	10	50	2 705.7	25	25	2 935.7	20	....
2 592.9	150	3	2 707.5	10	50	2 937.9	25	....
II 2 593.7p†LC	200R	1000R	2 708.5	15	50	2 939.3G$_2$A$_2$	50	....
2 595.8	200	25	2 711.6	2	125	2 940.4	40	....
2 596.8	....	50R	2 713.3	300	....	2 940.5	40	....
2 602.7	....	80	2 722.1	1	50	2 941.0	25	1
			2 724.5	2	80	2 949.2S$_1$G$_3$A$_1$	100	30

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

MANGANESE (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 956.1	20	1	3 251.1	50	25	3 610.3	60	40
2 963.6	20	....	3 252.9	75	50	3 619.3	75	50
2 986.0	20	....	3 254.0	50	25	3 623.8	75	40
3 007.7	40	40	3 256.1	75	50	3 629.7	100	30
3 011.2	25	25	3 258.4	75	40	3 641.4	50	50
3 011.4	25	25	3 260.2	75	50	3 660.4	75	75
3 016.5	25	25	3 264.7	75	50	3 669.8	30	30
3 022.7	50	25	3 267.9	40	40	3 670.5	25	15
3 040.6	50	25	3 268.7	30	30	3 675.7	20	....
3 041.2	25	25	3 270.4	30	30	3 677.0	60	100
3 042.7	25R	25	3 273.0	20	20	3 682.1	25	40
3 043.4	40	40	3 278.6	60	30	3 692.8	50	50
3 044.6	100	40	3 280.8	60	30	3 693.7	50	60
3 045.6	40	20	3 296.0	20	....	3 696.6	100	50
3 045.8	25	12	3 296.9	60	30	3 701.7	60	30
3 047.0	60	60	3 298.2	50	25	3 706.1	75	5
3 048.9	25	....	3 303.3	40	....	3 718.9	75	100
3 054.4	75	40	3 308.8	20	....	3 728.9	75	100
3 062.1	75	20	3 311.9	75	....	3 731.9	75	100
3 066.0	75	....	3 313.2	50	....	3 736.9	25	25
3 070.3	100	25	3 314.4	30	....	3 746.6	25	25
3 073.1	75	20	3 314.9	35	....	3 750.8	60	30
3 079.6	125	40	3 316.5	20	....	3 756.6	20	20
3 081.3	75	25	3 317.3	100	30	3 763.4	20	20
3 082.1	50	....	3 320.7	60	30	3 763.8	40	25
3 097.1	75	40	3 330.7	75	....	3 776.5	25	25
3 100.3	60	60	3 343.7	30	....	3 790.2	100	125
3 101.6	50	50	II 3 439.0	20	20	3 799.3	50	50
3 110.7	35	35	II 3 442.0L	75	75	3 800.6	60	60
3 115.5	50	25	II 3 460.3	60	500	3 801.9	20	20
3 120.3	50	....	II 3 474.0	20	....	3 806.7	50	20
3 142.7	50	....	II 3 474.1	12	400	3 809.5	150	....
3 148.2	150	40	3 482.9	50	250	3 809.6	150	150
3 161.0	150	50	3 488.7	50	200	3 816.8	60	50
3 178.5	150	50	I 3 493.0	1000R	100	3 823.5	75	75
3 206.9	60	....	II 3 495.8	25	150	3 823.9	50	50
3 212.9	100	100	II 3 497.5	15	150	3 829.7	60	60
3 216.9	75	75	3 531.8	40R	30R	3 833.9	75	75
3 224.8	75	40	3 532.0	50	8	3 834.4	75R	75
3 226.0	40	20	3 532.1	50	30	3 839.8	100	125
3 228.1	100	100	3 547.8	40	15	3 841.1	50	50
3 230.7	75	75	3 548.0	40	15	3 844.0	75	100
3 234.0	75	....	3 548.2	40	40	3 853.5	25	20
3 235.0	30	....	3 569.5	25	8	3 889.5	25	50
3 236.8	75	75	3 570.0	20R	....	3 892.6	20	20
3 237.4	30	....	3 570.1	20R	15	3 894.7	40	40
3 240.4	60	30	3 577.9	50	250	3 898.4	30	....
3 240.6	60	30	3 586.5	50	40	3 911.1	20	....
3 243.8	100	75	3 595.1	50	25	3 918.3	40	50
3 247.5	125	....	3 607.5	75	40	3 922.7	20	....
3 248.5	100	100	3 608.5	60	40	3 924.1	20	20

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

MANGANESE (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 926.5	40	50	4 137.3	40	5	4 464.7	60	50
3 929.2	30	30	4 141.1	50	30	4 470.1	80	40
3 936.8	25	50	4 147.5	40	20	4 472.8	100	25
3 942.9	75	75	4 148.8	50	30	4 479.4	60	....
3 952.0	40	50	4 155.5	40	5	4 490.1	100	25
3 952.8	60	75	4 157.0	40	2	4 491.7	50	5
3 975.9	40	50	4 176.6	100	40	4 496.6	40	5
3 977.1	50	100	4 190.0	80	40	4 498.9	150	40
3 982.6	20	30	4 201.8	40	20	4 502.2	125	40
3 982.9	20	30	4 211.7	30	20	4 503.9	60	5
3 984.2	20	20	4 220.6	60	20	4 523.4	50	....
3 985.2	75	100	4 235.1	80	....	4 529.8	50	....
3 986.8	40	75	4 235.3	80	100	4 534.5	30	....
3 987.1	30	60	4 239.7	100	50	4 538.5	40	....
3 991.6	20	25	4 257.7	100	40	4 542.4	80	5
3 992.5	40	75	4 261.3	20	5	4 544.4	60	5
4 003.3	20	5	4 265.9	100	50	4 548.6	80	5
4 018.1	80	60	4 281.1	100	50	4 560.5	20	....
4 026.4	50	40	4 284.1	80	20	4 571.2	20	....
I 4 030.8P**B_1C	500R	20	4 300.2	60	5	4 572.7	20	....
I 4 033.1p††B_2C	400R	20	4 305.7	50	....	4 575.4	50	....
I 4 034.5p‡‡B_3C	250R	20	4 312.6	100	20	4 579.7	50	....
4 035.7	50	60	4 321.2	60	5	4 581.8	125	....
4 041.4	100	50	4 323.4	50	....	4 582.8	20	....
4 048.8	60	60	4 326.8	80	30	4 584.9	20	....
4 052.5	20	20	4 337.4	80	....	4 586.1	30	....
4 055.5	80	80	4 365.2	25	5	4 605.4	150	15
4 058.0	80	20	4 368.9	50	....	4 607.6	50	....
4 058.9	80	60	4 374.9	150	20	4 609.9	20	....
4 059.4	20	15	4 381.7	80	20	4 619.3	20	....
4 061.7	80	30	4 382.6	80	....	4 625.4	20	....
4 063.5	100	60	4 388.1	60	....	4 626.5	80	15
4 065.1	20	20	4 389.8	50	....	4 627.7	50	....
4 068.0	50	20	4 408.1	60	5	4 642.8	50	....
4 070.3	80	30	4 410.5	50	....	4 645.0	40	....
4 075.3	25	5	4 411.9	100	20	4 658.8	25	....
4 079.2	50	40	4 414.9	150	60	4 671.7	100	5
4 079.4	50	40	4 419.8	100	20	4 701.2	100	5
4 082.9	80	60	4 436.4	80	50	4 709.7	150	15
4 083.6	80	60	4 447.1	60	....	4 727.5	150	20
4 089.9	80	20	4 451.6	125	100	4 739.1	150	15
4 092.4	30	20	4 453.0	50	20	4 754.0	400	60
4 103.0	100	20	4 455.0	25	10	4 761.5	60	15
4 105.4	50	20	4 455.3	25	15	4 762.4	100	40
4 107.9	20	5	4 455.8	25	15	4 765.9	60	25
4 110.9	80R	40	4 457.0	20	10	4 766.4	80	30
4 113.2	40	20	4 457.6	20	15	4 774.1	50	....
4 113.9	20	5	4 458.3	25	20	4 783.4	400	60
4 114.4	20	20	4 460.4	20	5	4 797.7	25	....
4 131.1	50	40	4 461.1	30	25	4 808.7	20	....
4 135.0	50	30	4 462.0	40	60	4 823.5	400	80

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

MANGANESE (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
4 825.6	20	5	5 420.4	60	....	6 605.5	30	....
4 838.2	50	....	5 432.5	40	....	6 691.6	25	....
4 840.1	50	....	5 457.5	25	....	6 833.9	40	....
4 844.3	80	5	5 470.6	50	....	6 887.8	30	....
4 854.8	30	5	5 481.4	50	....	6 931.1	20	....
4 862.1	40	5	5 505.9	40	....	6 942.5	100	....
4 934.2	25	5	5 516.8	50	....	6 989.8	80	....
4 965.9	50	2	5 537.8	40	....	7 069.8	60	....
5 004.9	20	....	6 013.5	100	5	7 151.3	30	....
5 117.9	30	....	6 016.6	80	5	7 184.3	40	....
5 150.9	40	....	6 021.8	80	5	7 247.8	40	....
5 196.6	30	....	6 379.0	20	....	7 283.8	400	....
5 255.3	50	....	6 382.2	20	....	7 302.9	300	....
5 341.1	200	100	6 384.7	25	....	I 7 326.5	500	....
5 349.9	20	....	6 414.0	25	....	7 667.9	20	....
5 377.6	40	....	6 441.0	60	....	I 7 680.2	200	....
5 394.7	50	....	6 491.7	100	....	I 7 712.4	100	....
5 399.5	40	....	6 518.8	20	....	I 7 733.2	60	....
5 407.4	60	....	6 519.4	20	....	I 7 734.4	20	....
5 413.7	30	....	6 586.3	20	....	I 7 764.7	200	....

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Al 3082.2	*Al Hg Pb W Th Fe Co Ag Ir Mn	¶Mg 2795.5 Pb 2833.1	¶Au Cr Hg Mg Pb Sc Zn
†Ge 2709.6	†Bi Fe Mo Na Sn	**Ga 4172.1	**Cr Fe Ga Mo Pt Sc Zr Th V Ta Ti
‡Fe 2611.9	‡Ag Co Cr Fe Tl		
§W 2848.0	§Au Fe Mg Mo Pt V U Co	††Ga 4172.1	††Co Cr Fe Ga Mo Sb Sr U Ta Ti
‖Mg 2779.9 Mg 2802.7	‖Bi Hg Mg Mo Pb	‡‡Ga 4172.1	‡‡Co Fe Ga Mo Ni Pt Cb Ti W Th Cr Ir

Control lines:
S_1Cu 2858.0
2997.4
2882.9
2961.2
A.Al 2816.2
A_1 3050

Control lines:
S_2Cu 4249.0
S_3Cu 4249.0
G_1Fe 2923.8
G_2Fe 2923.8
A_2Mg 2916

Control lines:
G_3Fe 2944.4
B_1Fe 4009
B_2Fe 4014
B_3Fe 4021
X Mo 2649
3158

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

MERCURY

Hg

Wavelength	Arc	Spark and Dis-charge	Wavelength	Arc	Spark and Dis-charge	Wavelength	Arc	Spark and Dis-charg
II 2 224.7	....	30	2 820.0	10	20	I 4 358.4‡C	3000	500
I 2 302.1	15	15	I 2 847.8	15	100	I 4 827.1	....	15
I 2 323.2	10	5	I 2 857.0	20	10	I 4 890.3	....	15
II 2 345.6	10	30	I 2 893.6	40	50	I 4 916.0	....	50
I 2 352.5	12	15	I 2 925.4	60	50	I 4 991.5	15	....
I 2 374.0	10	....	2 967.3B_1	100	100	I 5 025.6	....	20
2 378.3	20	20	I 2 967.6	10	....	5 045.8	....	15
I 2 380.0	10	10	I 3 021.5B_2	80	40	I 5 102.4	....	10
I 2 399.4	20	10	I 3 023.5	60	10	I 5 120.5	....	20
I 2 399.7	10	15	I 3 025.6	15	10	I 5 138.1	....	10
I 2 464.1	15	15	I 3 027.5	25	15	I 5 218.9	....	10
I 2 478.7	15	15	I 3 125.7	200	150	I 5 290.1	....	10
I 2 482.0	30	5	I 3 131.5	400	300	I 5 354.0	....	30
I 2 482.7	25	10	I 3 131.8	200	100	5 365.1	....	20
I 2 483.8	30	5	3 135.8	10	....	I 5 384.7	....	15
I 2 484.8	30	30	I 3 144.5	10	....	I 5 460.7	....	1000
I 2 534.8	30	30	I 3 341.5	100	100	I 5 549.8	....	15
I 2 536.5P*LC	2000R	1000R	3 351.3	10	20	I 5 675.9	....	80
I 2 576.3	20	15	3 390.1	....	50	I 5 769.6	600	200
I 2 603.2	20	20	II 3 478.9	10	....	I 5 789.7	....	500
I 2 625.2	10	15	3 561.2	10	6	I 5 790.6	....	1000
I 2 634.8	20	12	I 3 650.1†	200	500	I 5 803.5	....	70
I 2 642.6	10	....	I 3 654.8	....	200	I 5 821.5	....	15
I 2 642.8	15	....	I 3 662.9	50	400	I 5 859.3	....	30
I 2 652.0	100	60	I 3 663.3	500	400	I 5 872.0	....	10
I 2 653.7	80	40	I 3 701.4	15	2	5 890.2	....	40
I 2 655.1	80	40	I 3 704.2	20	20	6 072.6	....	10
I 2 698.9	25	30	I 3 701.7	15	2	6 123.3	....	15
I 2 699.5	25	....	I 3 906.4	25	15	I 6 234.4	....	15
I 2 752.2	100R	50	I 4 046.6	200	300	II 6 715.2	....	25
2 752.8	40	10	I 4 077.8	150	150	I 6 716.2	....	80
I 2 759.7	20	15	I 4 108.0	20	5	I 6 907.2	....	125
I 2 799.8	10	10	I 4 339.2	150	20	I 7 081.9	....	125
I 2 803.5	20	20	I 4 343.6	20	5	I 7 092.0	....	100
I 2 804.5	18	10	I 4 347.5	200	50	I 7 371.7	....	80

Control lines:		Interfering lines:
*Fe	2539.0	*Co Fe P Pb Pt W Bi Rh Mo Ta
Fe	2538.8	
W	2533.0	
Co	2432.2	
Fe	2541.0	
Mo	2646.5	
Ti	2534.6	
†Fe	3631.5	†Cd Cr Fe Mo Sc

Control lines:		Interfering lines:
Sc	2813.7	
Ti	3234.5	
Ti	3239.0	
‡Fe	4401.3	‡Al Ba Co Cr Fe Mg Ni Pt Sc Ti V Mo Ta Ca Y
Cr	4371.3	
B_1Sn	3009.1	
B_2Sn	2863.3	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

MOLYBDENUM

Mo

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 020.3	20	50R	2 807.8	60	80	3 170.3†C	1000R	25R
2 273.3	....	100	II 2 816.2PL**C	200	300	3 172.7	3	50
2 304.3	7	50	II 2 848.2pB$_1$	125	200	3 175.0	2	60
2 332.1	8	80	2 849.4	50	5	3 176.3	....	50
2 340.5	30	50	2 853.2	5	100R	3 187.6	1	50
2 341.6	9	60	2 853.3	25	100	3 192.1	3	50
2 410.1	....	60	2 863.8	30	100	3 194.0‡C	1000R	50R
2 422.2	2	60	II 2 871.5p	100	100	3 196.0	12	50
2 436.0	10	50	2 872.9	2	50	3 208.8C	150R	60
2 437.7	10	80	2 874.8	2	60	3 214.4	20	50
2 457.8	10	60	2 879.0	15	100	3 216.1	....	50
2 472.0	50	2	II 2 891.0	30	50	3 229.7	....	50
2 477.6	2	50	2 894.5	50	80	3 233.1	50	30
2 481.8	50	....	2 903.1	20	100	3 240.7	3	60
2 538.5	30	125	II 2 909.1	25	40	3 250.7	2	100
2 572.3	60	10	2 911.9	30	50	3 253.8	1	50
2 578.9	2	60	2 913.8	1	50	3 254.7	8	50
2 602.8	25	100	2 923.4	30	30	3 270.9	50	25
2 607.4	50	5	2 930.5	25	50	3 271.7	....	60
2 629.9	50	6	2 934.3	20	50	3 278.9	1	50
2 636.7	25	150	2 944.8	2	50	3 290.8	40	100
2 638.8	20	125	2 972.6	20	50	3 292.3	10	300
2 644.4	30	60	2 986.2	4	50	3 297.7	1	60
2 646.5	25	100	3 003.8	100	5	3 307.4	....	50
2 653.3	25	150	3 014.2	5	50	3 312.9	1	50
2 655.0	50	8	3 018.6	1	100	3 313.6	5	50
2 660.6	25	125	3 023.3	5	100	3 320.9	3	80
2 671.8	1	100	3 025.0	50	4	3 325.7	50	25
2 672.8	15	100	3 046.8	50	2	3 327.3	40	20
2 673.3	1	100	3 047.3	50	4	3 329.2	2	100
2 681.4	10	100	3 052.3	10	50	3 332.5	....	80
2 683.2	20	150	3 055.3	50	5	3 344.7	50	40
2 684.1	40	150	3 061.6	50	3	3 346.4	2	50
2 688.0	30	100	3 064.3	80	10	3 347.0	40	4
2 701.4	20	100	3 067.6	10	50	3 358.1C	60	30
2 704.9	1	50	3 074.4	60	15	3 368.0	2	100
2 717.4	30	100	3 077.7	20	125	3 384.6	30R	25
2 727.0	10	100	3 080.4	60	6	3 402.8	5	100
2 729.7	15	60	3 085.6	125	25	3 434.8	50	12
2 730.2	2	60	3 087.6	30	200	3 435.4	....	60
2 750.0	2	50	3 092.1	40	100	3 447.1	25R	20
2 751.5	50	5	3 094.7	150	25	3 504.4	20	20
2 756.1	10	50	3 101.3	80	70	3 524.6	5	50
2 763.6	25	50	3 116.1	1	60	3 537.1	....	50
2 769.8	10	100	3 122.0	5	150	3 614.3	50	30
2 774.4	30	50	3 132.6*C	1000R	300R	3 623.7	....	50
2 775.4	80	100	3 152.8	6	80	3 635.1	100	10
2 780.0	60	100	3 155.6	....	50	3 651.1	2	50
2 785.0	100	200	3 158.2C	200R	30R	3 688.3	4	150

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

MOLYBDENUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 692.6	3	150	4 326.1	50	40	5 360.6	100	70
3 702.6	10	150	4 326.7	50	50	5 364.3	70	25
3 744.4	20	80	4 350.3	50	40	5 473.4	50	25
3 748.1	1	50	4 363.6	5	200	5 506.5	200R	100
3 755.5	1	50	4 377.8	5	200	5 533.0	200	100
3 782.1	....	100	4 381.6	150	150	5 570.5	200	100
3 786.4	2	125	4 411.7	25	25	5 632.5	100	50
I 3 798.3P§C	1000R	1000R	4 412.7	30	20	5 650.1	90	50
3 833.7	80	25	4 433.5	4	105	5 689.1	80	40
3 837.3	....	100	4 435.0	80	80	5 722.7	80	60
3 857.2	....	60	4 457.4	50	50	5 751.4	125	100
I 3 864.1p‖C	1000R	500R	4 468.3	25	25	5 791.8	100	60
3 871.4	....	50	4 474.6	125	125	5 848.9	50	....
I 3 903.0p¶C	1000R	500R	4 474.7	80	....	5 849.7	70	10
3 915.4	6	50	4 491.3	40	30	5 858.3	200	200
3 941.5	5	150	4 524.3	30	30	5 869.3	50	....
3 961.5	5	500	4 526.4	25	25	5 888.3	150	100
3 968.7	8	50	4 536.8	40	80	5 890.0	50	....
4 062.1	80	80	4 576.5	40	40	5 893.4	70	15
4 069.9	25	25	4 595.2	40	40	5 926.4	70	20
4 070.0	25	25	4 621.4	30	25	5 928.9	100	....
4 081.4	50	50	4 626.5	100	80	6 030.7	300	125
4 084.4	40	40	4 627.5	80	80	6 357.2	40	10
4 102.1	30	25	4 707.3	125	125	6 424.4	100	20
4 119.6	5	50	4 717.9	50	50	6 471.2	50	4
4 120.1	25	50	4 731.4	100	100	6 519.8	25	6
4 122.4	15	50	4 760.2	125	125	6 619.1	300	15
4 125.6	....	50	4 764.4	50	50	6 650.4	80	6
4 128.3	50	25	4 811.1	50	50	6 734.0	100	4
4 143.5	100	100	4 819.2	80	60	6 746.3	50	3
4 185.8	40	40	4 830.5	125	100	6 829.0	50	....
4 188.3	100	80	4 839.6	20	20	6 838.9	30	2
4 209.6	4	80	4 868.0	50	40	6 886.3	25	....
4 232.6	125	100	4 903.8	80	30	6 914.0	40	....
4 244.8	4	80	4 950.6	80	30	6 989.0	30	....
4 250.7	5	125	4 957.5	60	25	7 060.2	25	....
4 251.9	60	60	4 977.7	50	3	7 109.9	80	....
4 276.9	30	30	4 979.1	100	30	7 134.0	40	....
4 277.2	30	30	4 999.9	50	25	7 242.5	80	....
4 277.4	15	15	5 172.9	70	25	7 245.9	60	....
4 279.0	8	100	5 174.2	70	25	7 391.4	50	....
4 284.6	125	80	5 238.2	80	30	7 485.7	100	....
4 288.6	80	100	5 240.9	80	40	7 656.8	25	....
4 292.1	100	100	5 242.8	50	20	7 720.8	50	....
4 293.2	125	100	5 259.0	60	20	7 829.7	20	....
4 293.9	20	20	5 280.9	50	25			

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Be 2348.6 Cr 2849.8 Hg 3650.2	*Au Be Cd Cr Fe Sc Te V	‖Fe 3869.6 Fe 3895.7 Fe 3820.4	‖Bi Cr Fe Mn Sr V Zr W Ti Co

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

MOLYBDENUM (*Continued*)

Control lines:	Interfering lines:	Control lines:	Interfering lines:
Ni 3012.0		¶Fe 3895.7	¶Cr Fe Hg Mn
†Ti 3242.0	†Cu Fe Mn V W Th Ag U Ta Ce	Fe 3899.7	**Ta Th V Mo Mn
‡Cr 3180.7	‡Au Cu Fe Mn V	Fe 3856.4	
Fe 3222.1		Si 2519.2	
V 3267.7		Ti 3948.7	
§Ce 4186.6	§Cr Fe Mg Pd Sn Ti U Zn Cb	B_1Cr 2849.8	
Fe 3795.0			

NEODYMIUM

Nd

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 133.6	15	10	3 941.5	60	30	4 646.4	50	....
3 275.2	15	8	3 951.2p	40	30	4 646.7	60	4
3 300.1	10	6	3 953.5	60	60	4 674.6	50	10
3 328.8	15	6	3 957.5	60	40	4 680.7	50	1
3 382.8	200	10	3 963.1	30	25	4 683.4	50	1
3 388.0	10	4	3 990.1	40	20	4 706.5	50	5
3 555.7	100	15	3 991.7	60	40	4 719.0	50	....
3 563.4	50	10	3 994.7	80	40	4 811.3	60	60
3 590.4	400	300	4 012.3	80	40	4 825.5	100	8
3 592.6	20	30	4 109.5L	30	30	4 859.0	60	60
3 609.8	15	10	4 177.3	15	25	4 883.8	60	....
3 735.6	10	50	4 232.4	40	15	4 896.9	60	....
3 769.6	100	20	4 327.9	30	15	4 913.4	60	....
3 780.4	20	15	4 351.3	30	10	4 920.7	60	....
3 801.4	60	40	4 358.2	50	20	4 924.5	80	....
3 805.4	50	30	4 368.6	50	15	4 944.8	50	....
3 821.8	50	40	4 375.0	30	5	4 954.8	50	....
3 828.2	50	40	4 385.7	40	20	5 192.6	40	....
3 829.4	50	40	4 400.8	50	20	5 234.2	50	....
3 831.0	60	30	4 411.1	50	20	5 249.6	60	2
3 833.0	60	30	4 424.3	50	50	5 255.5	50	3
3 836.5	80	100	4 446.4	100	50	5 293.2	60	4
3 838.7	50	25	4 451.6	100	50	5 319.8	60	2
3 847.9	60	50	4 452.0	50	20	5 361.5	25	1
3 852.4	60	50	4 463.0	60	20	5 431.5	25	2
3 863.4	20	20	4 501.8	50	8	5 485.7	20	3
3 875.9	30	4	4 506.6	50	3	5 594.4	150	5
3 889.7	30	25	4 511.8	50	10	5 620.5	200	5
3 889.9	30	20	4 541.3	50	4	5 688.5	150	....
3 890.6	30	25	4 542.1	50	5	5 708.3	60	....
3 890.9	20	20	4 542.6	50	5	5 729.3	30	....
3 891.5	20	15	4 560.4	50	3	5 804.0	100	....
3 892.1	20	20	4 563.2	50	4	6 007.7	25	....
3 894.6	20	20	4 579.3	25	3	6 310.5	50	....
3 905.9	40	30	4 586.6	50	....	6 385.2	100	....
3 927.1	80	50	4 634.2	50	....	6 485.7	20	....
3 934.8	60	30	4 641.1	80	....	6 630.1	30	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

NICKEL

Ni

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 019.0	2	30	2 436.7	30	20	II 2 690.6	1	250
II 2 021.0	....	30	II 2 437.9	40	200	I 2 696.5	2	50
II 2 029.2	....	25	I 2 450.5	20	....	II 2 708.8	....	500
I 2 063.4	20	2	2 451.0	100	30	II 2 743.0	....	500
I 2 069.5	20	2	I 2 454.0	40	8	I 2 746.7	125	....
I 2 082.9	25	2	I 2 465.3	20	5	II 2 759.0	....	500
I 2 089.0	30	....	I 2 467.0	40	....	II 2 768.8	....	250
I 2 095.7	25	2	I 2 473.2	80	500	II 2 775.3	....	250
II 2 111.7	25	9	I 2 476.9	40	2	I 2 798.7	125	....
I 2 121 4	20	8	II 2 484.3	....	50	2 802.3	50	15
2 124.1	30	....	I 2 489.5	40	6	I 2 805.1	50	15
I 2 124.8	25	3	2 490.7	40	....	II 2 805.7	....	200
II 2 165.6	20	40R	2 491.2	20	....	I 2 821.3	125	125
II 2 169.1	20	20	2 501.1	20	....	II 2 825.2	....	125
I 2 190.2	20	3	II 2 505.8	....	50	I 2 834.6	40	15
I 2 197.4	20	....	II 2 510.9	50	250	I 2 839.0	25	....
II 2 206.7	20	30	I 2 524.2	50R	....	II 2 842.4	....	150
II 2 216.5	20	40	II 2 525.4	....	300	II 2 863.7	....	250
I 2 244.5	40	....	I 2 528.1	20	....	II 2 864.2	....	300
II 2 253.9	100	300	2 529.0	20	2	I 2 907.5	40	....
I 2 259.6	300	....	I 2 532.1	30	....	2 914.0	20	....
II 2 264.5	150	400	2 536.0	25	....	I 2 943.9	50R	20
I 2 266.4	20	2	I 2 540.0	40	1	I 2 981.7	80R	20
II 2 270.2	100	400	II 2 545.9	20	900	I 2 984.1	50R	10
II 2 279.5	20	....	II 2 547.2	....	100	I 2 992.6S_1	80R	10
II 2 287.1	100	500	I 2 547.4	20	....	I 2 994.5	125R	10
I 2 290.0	20R	20	I 2 553.4	20	....	I 3 002 5*C	1000R	100
I 2 311.0	50R	10	2 559.7	20	....	I 3 003.6	500R	80
I 2 312.3	30	6	I 2 561.4	40	....	I 3 012.0S_2	800R	125
I 2 317.2	30R	12	I 2 578.5	20	....	I 3 019.1	200R	30
I 2 320.0	30R	5	II 2 588.3	....	80	I 3 031.9	200	....
I 2 321.4	20R	10	II 2 601.1	....	2000	I 3 037.9	800R	100
I 2 325.8	30R	9	II 2 605.3	....	250	I 3 045.0	200	10
II 2 336.6	....	150	II 2 606.4	....	600	I 3 050.8†S_3C	1000R	....
II 2 375.4	10	30	II 2 610.1	....	900	I 3 054.3C	400R	100
I 2 386.6	20	5	II 2 611.7	....	125	I 3 057.6C	400R	125
II 2 394.5	18	20	II 2 615.2	....	900	I 3 064.6	200R	50
I 2 401.8	40R	10	II 2 626.6	....	500	I 3 080.8	200	60
II 2 405.2	....	80	II 2 630.3	....	150	II 3 087.1	....	150
I 2 412.6	20	8	II 2 631.5	....	100	I 3 097.1	200	50
II 2 413.0	....	50	II 2 632.9	....	2000	I 3 099.1	200	50
II 2 416.1L	40	250	II 2 647.1	....	500	I 3 101.6	1000R	150
I 2 419.3	20R	4	II 2 648.7	....	80	I 3 101.9C	400R	150
I 2 421.2	20	4	II 2 655 5	....	400	I 3 105 5	200	35
I 2 423.2	25	4	II 2 655.9	....	500	I 3 107.7	25	....
I 2 423.7	20	5	II 2 665.2	....	125	I 3 114.1	300	50
I 2 424 0	20	....	II 2 670 3	....	80	I 3 129.3	125	....
II 2 433.6	....	80	II 2 679.2	....	500	I 3 134.1S_4	1000R	150
I 2 434.4	40	....	II 2 684 4	....	600	I 3 145.7	200	3

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

NICKEL (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 3 181.7	50	1	I 3 420.7	30	3	I 3 730.8	25	....
I 3 183.3	25	....	I 3 421.3	30	8	I 3 736.8	300	15
I 3 184.4	150	3	I 3 423.7	600R	25	I 3 739.2	100	10
I 3 185.6	125	....	I 3 433.6L	800R	50	I 3 749.0	50	5
I 3 197.1S_5	300	....	I 3 437.3	600R	40	II 3 769.5	2	50
3 200.4	30	....	I 3 446.3C	1000R	50	I 3 775.6	500	40
I 3 202.1	25	....	I 3 452.9	600R	50	I 3 778.1	25	5
I 3 209.9	20	....	I 3 458.5C	800R	50	I 3 783.5	500	40
I 3 221.3	35	....	I 3 461.7§C	800R	50	I 3 792.3	25	5
I 3 221.7	300	4	I 3 467.5	300	15	I 3 793.6	50	....
I 3 225.0	300	6	I 3 469.5	300	20	I 3 807.1	800	40
I 3 226.9	100	....	I 3 472.5	800R	40	3 831.7	300	10
I 3 233.0	300R	35	I 3 483.8	500R	30	I 3 832.9	25	....
I 3 234.6	300	15	I 3 485.9	150	30	I 3 858.3	800R	70
I 3 243.1	400R	15	I 3 493.0p‖B_2C	1000R	100	I 3 889.7	30	10
I 3 238.5	150	2	I 3 500.9	500	80	I 3 970.5	40	....
I 3 239.4	30	....	I 3 502.6	100	....	I 3 972.2	100	6
I 3 250.7	125	1	I 3 507.7	100	12	I 3 973.6	800	10
I 3 271.1	125	1	I 3 510.3	900R	50	I 3 974.7	40	....
I 3 281.9	20	....	I 3 513.9	200	40	I 3 984.1	30	....
I 3 282.7	100	....	I 3 515.1p¶B_3C	1000R	50	I 3 994.0	30	....
I 3 282.8	25	1	I 3 518.6	90	8	I 3 995.5	30	....
I 3 286.9	100	1	I 3 519.8	500	30	I 4 200.5	40	....
I 3 305.0	25	....	I 3 523.4	100	....	I 4 201.7	30	....
I 3 310.2	50	....	I 3 524.5p**C	1000R	100	I 4 284.7	25	10
I 3 312.3	70	2	I 3 528.0	200	15	I 4 288.0	150	....
I 3 315.7	400R	20	I 3 530.6	30	....	I 4 295.9	100	2
I 3 320.3	400	15	I 3 548.2	400	25	I 4 325.6	70	....
I 3 322.3	400	10	I 3 551.5	50	12	I 4 331.6	200	12
I 3 359.1	60	....	I 3 553.5	50	10	I 4 359.6	100	10
I 3 361.6	500	20	I 3 561.8	70	12	I 4 384.5	25	1
I 3 362.8	100	....	I 3 566.4	2000R	100	I 4 401.5	1000	30
I 3 363.6	20	....	I 3 571.9	1000R	40	I 4 410.5	25	4
I 3 365.8	400	12	I 3 587.9	200	12	I 4 459.0	400	20
I 3 366.2	400	12	I 3 597.7	1000R	50	I 4 462.5	150	20
I 3 366.8	60	1	I 3 602.3	150	15	I 4 470.5	15	20
I 3 367.9	80	....	I 3 606.9	100R	....	I 4 520.0	25	....
I 3 369.6	500R	100	I 3 609.3	200	15	I 4 546.9	50	2
I 3 372.0	400	10	I 3 610.5	1000R	....	I 4 547.2	30	....
I 3 374.2	400	6	I 3 612.7	400	50	I 4 592.5	200	2
3 376.3	25	....	I 3 619.4††LB	2000R	150	I 4 600.4	200	....
I 3 380.6	600R	100	I 3 624.7	150	15	I 4 605.0	300	10
I 3 380.9	200	12	I 3 634.9	50	10	I 4 606.2	100	....
I 3 391.1	400	40	I 3 662.0	50	6	I 4 648.7	400	3
I 3 393.0	600R	....	I 3 664.1	300	30	I 4 655.7	40	....
I 3 401.2	40	1	I 3 669.2	150	10	I 4 667.0	50	....
I 3 403.4	40	....	I 3 670.4	150	20	I 4 667.8	100	....
I 3 409.6	300	....	I 3 674.2	200	50R	I 4 686.2	200	1
I 3 413.5	500	15	I 3 688.4	150	15	I 4 698.4	30	....
I 3 413.9	300	10	I 3 693.9	50	....	I 4 701.3	100	....
I 3 414.8P‡B_1C	1000R	50	I 3 722.5	200	20	I 4 701.5	150	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

NICKEL (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spar
I 4 703.8	200	....	I 5 035.4	300	5	I 5 641.9	25	....
I 4 714.4	1000	8	I 5 036.0	70	....	I 5 682.2	50	....
I 4 715.8	200	2	I 5 038.6	50	....	I 5 695.0	40	....
I 4 731.8	100	2	I 5 039.3	20	....	I 5 709.6	100	....
I 4 732.5	100	....	I 5 041.1	30	....	I 5 711.9	50	....
I 4 752.1	30	....	I 5 042.2	80	....	I 5 715.1	50	....
I 4 752.4	150	....	I 5 048.1	20	....	I 5 748.3	40	....
I 4 754.8	100	....	I 5 048.9	80	2	I 5 754.7	150	....
I 4 756.5	250	3	I 5 051.5	50	....	I 5 760.8	50	....
I 4 762.6	150	1	I 5 058.0	20	....	I 5 805.2	50	....
I 4 764.0	150	1	I 5 080.0	30	....	I+5 857.7	50	....
I 4 786.5	300	2	I 5 080.5	200	3	I+5 892.8	6	....
I 4 807.0	150	1	I 5 081.1	150	2	I 6 007.3	20	....
I 4 808.9	25	....	I 5 082.4	100	....	I 6 086.3	100	....
I 4 821.1	25	2	I 5 084.1	300	2	I 6 108.1	200	....
I 4 829.0	300	2	I 5 088.5	20	....	I 6 111.1	25	....
I 4 831.2	200	2	I 5 089.0	20	....	I 6 116.2	150	....
I 4 832.7	70	....	I 5 094.4	25	....	I 6 163.4	100	....
I 4 838.7	150	4	I 5 096.9	50	....	I 6 175.4	300	....
I 4 843.2	20	....	I 5 099.3	80	....	I 6 176.8	400	....
I 4 852.7	150	....	I 5 099.9	150	....	I 6 186.7	30	....
I 4 855.4	400	....	I 5 103.0	40	....	I 6 191.2	500	1
I 4 857.4	100	....	I 5 115.4	80	5	I 6 224.0	30	....
I 4 864.3	20	....	I 5 121.6	20	....	I 6 256.4	600	10
I 4 866.3	300	1	I 5 125.2	50	....	I 6 314.7	300	....
I 4 870.8	100	....	I 5 129.4	80	....	I 6 327.6	25	....
I 4 873.4	200	2	I 5 137.1	150	1	I 6 339.1	50	....
I 4 874.8	25	....	I 5 139.3	50	....	I 6 378.3	20	....
I 4 887.0	30	....	I 5 142.8	100	....	I 6 482.8	35	....
I 4 904.4	400	1	I 5 146.5	150	1	I 6 586.3	40	....
I 4 912.0	100	....	I 5 155.1	50	....	I 6 643.6	300	....
I 4 914.0	200	....	I 5 155.8	80	1	I 6 767.8	300	....
I 4 918.4	200	1	I 5 168.7	70	....	I 6 772.4	200	....
I 4 925.6	100	....	I 5 176.6	70	2	I 6 813.6	30	....
I 4 935.8	150	1	I 5 184.6	50	....	I 6 842.1	60	....
I 4 937.3	400	....	I 5 235.4	30	2	I 6 914.6	300	....
I 4 945.5	90	....	I 5 353.4	40	....	I 6 955.1	80	....
I 4 953.2	150	....	I 5 371.4	30	....	I 7 001.6	30	....
I 4 971.4	100	....	I 5 411.2	40	2	I 7 024.9	50	....
I 4 980.2	500	1	I 5 424.7	30	....	I 7 030.1	100	....
I 4 984.1	500	1	I 5 435.9	50	....	I 7 034.4	30	....
I 4 996.9	80	....	I 5 462.5	20	....	I 7 063.0	35	....
I 4 998.2	150	....	I 5 476.9	400	8	I 7 110.9	100	....
I 5 000.3	150	....	I 5 510.0	20	....	I 7 122.2	1000	....
I 5 003.8	20	....	I 5 578.7	50	....	I 7 167.0	35	....
I 5 010.0	25	....	I 5 587.9	50	....	I 7 182.0	200	....
I 5 011.0	50	....	I 5 589.4	20	....	I 7 197.0	200	....
I 5 012.5	70	2	I 5 592.3	150R	1	I 7 261.9	300	....
I 5 014.2	25	....	I 5 593.7	40	2	I 7 290.9	20	....
I 5 017.6	100	1	I 5 614.8	50	....	I 7 291.5	100	....
I 5 018.3	70	....	I 5 625.3	30	....	I 7 327.7	25	....

TABLE VI (*Continued*)

Principal Lines by Elements

NICKEL (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 7 381.9	40	....	I 7 522.8	40	....	I 7 715.6	40	....
I 7 385.2	150	....	I 7 525.1	30	....	I 7 727.7	80	....
I 7 386.2	100	....	I 7 555.6	40	....	I 7 789.0	60	....
I 7 393.6	600	....	I 7 574.1	30	....	I 7 797.6	80	....
I 7 409.4	400	....	I 7 617.0	60	....	I 7 863.8	20	....
I 7 414.5	200	....	I 7 619.2	20	....	I 7 917.5	30	....
I 7 422.3	600	....	I 7 714.3	60	....			

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Cr 3024.4	*Au Cu Fe Mn Mo V W	Mn 3442.0	
Fe 2994.4		‖Co 3409.2	‖Co Cr Mo Ti V W Mn Ce
†Cr 3030.3	†Al Co Cr Fe Hg Mg	Fe 3475.5	
Fe 2994.4		¶Co 3409.2	¶Be Co Fe Mo Pt Tl Zn Cb Be Ir U
‡Co 3409.2	‡Co Cu Ir Ca Fe Zr Ag V	**Co 3506.3	**Au Ba Co Cu Fe Hg Mo Tl V W Ti Mn Zr
§Cd 3610.5	§Cd Co Mn Ti V W	Fe 3558.5	
Co 3474.0		††Fe 3631.5	††Cr Cu Fe Mn Ti V

Control lines:	Control lines:	Control lines:
S_1Cu 2997.4	3142.4	B_1Fe 3415
S_2Cu 3010.8	3126.1	B_2Fe 3495
S_3Cu 3063.4	S_6Cu 3208.2	B_3Fe 3516
S_4Cu 3140.4		

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

OSMIUM

Os

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 045.4	50	20	2 720.0	75	15	3 086.3	50	10
2 118.0	80	20	2 721.9	75	10	3 087.7	50	10
2 119.8	125	30	2 732.8	75	15	3 088.3	60	12
2 137.1	100	30	2 761.4	50	10	3 090.1	100	15
2 156.3	50	3	2 796.7	100	15	3 090.3	100	12
2 158.5	50	25	2 804.1	80	20	3 090.5	80	15
2 159.5	60	....	2 806.9	100	1	3 093.6	125	15
2 160.0	60	5	2 814.2	50	25	3 101.5	125	20
2 161.0	50	1	I 2 838.6LC	100R	100	3 105.0	200	15
2 167.8	50	10	2 844.4	50	25	3 106.0	150	20
2 189.0	50	....	2 850.8	75	25	3 109.0	125	15
2 194.4	40	100	2 861.0	100	25	3 109.4	125	20
2 205.7	20	50	2 872.4	50	8	3 111.1	100	20
2 231.2	12	50	2 875.0	50	15	3 114.8	50	12
2 255.8	125	2	I 2 909.1*C	500R	400	3 116.5	50	15
2 260.1	25	50	2 912.3	50	50	3 118.1	80	15
2 261.7	25	50	2 919.8	100	15	3 118.3	150	20
2 270.2	60	15	3 003.5	60	12	3 124.9	150	10
2 272.5	4	50	3 013.1	150	20	3 129.2	60	15
2 279.1	100	25	3 015.7	100	15	3 131.1	125	30
2 282.3	100	125	3 017.2	100	25	3 140.3	60	12
2 283.7	50	15	3 018.0C	300R	50	3 140.9	50	12
2 336.8	50	80	3 019.4	100	20	3 146.0	60	10
2 350.2	30	50	I 3 030.7C	500	40	3 152.1	80	15
2 362.8	50	12	3 032.8	50	15	3 152.7	150	18
2 367.4	50	80	3 040.9	200	100	3 153.6	125	20
2 369.2	50	12	3 042.7	20	50	3 156.2	500R	15
2 371.2	50	15	3 043.5	100	15	3 156.8	100	3
2 377.0	50	30	3 043.6	60	12	3 157.2	100	2
2 377.6	50	15	3 044.4	50	10	3 161.4	80	12
2 396.8	100	12	3 044.9	100	12	3 161.7	100	10
2 423.1	25	80	3 049.5	80	15	3 164.6	60	12
2 425.0	50	8	3 050.4	100	50	3 166.5	200	20
2 461.4	50	10	3 051.2	80	15	3 168.3	100	15
2 480.0	15	100	3 055.0	50	10	3 173.2	100	15
2 488.5	50	15	3 055.2	80	15	3 173.9	80	30
2 492.4	50R	8R	3 058.7†C	500R	500	3 178.1	150	20
2 513.2	50	8	3 060.3	100	30	3 178.2	80	10
2 542.5	50	8	3 062.2	100	30	3 181.9	100	12
2 582.0	80	5	3 066.1	50	10	3 182.6	100	15
2 590.8	75	8	3 069.9	125	15	3 185.3	150	12
2 613.1	50	10	3 074.1	125	2	3 187.0	100	15
I 2 637.1C	150	30	3 075.0	125	20	3 187.3	80	12
2 644.1	75	10	3 077.1	100	12	3 189.5	125	15
2 658.6	50	10	3 077.4	80	8	3 194.2	125	15
2 689.8	50	10	3 077.7	100	30	3 194.7	50	10
2 699.6	50	8	3 078.1	125	15	3 195.4	100	12
2 706.7	50	8	3 078.4	125	15	3 213.3	50	40
2 714.6	50R	10	3 084.6	60	10	3 223.9	100	8

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

OSMIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 227.3	125	12	3 501.2	100	15	I 3 857.1	150	15
3 229.2	125	5	I 3 504.7	300	20	I 3 865.5	125	200
3 231.4	150	12	3 518.7	200	30	I 3 876.8	300	50
I 3 232.1	500R	20	3 523.6	150	30	3 878.6	50	12
3 232.5	150	10	3 526.0	80	20	3 881.9	125	20
3 234.2	150	12	I 3 528.6	400R	50	3 900.4	50	12
3 234.7	100	10	3 530.1	100	20	3 901.7	150	20
3 238.6	100	20	I 3 532.8	100	20	3 928.5	50	10
3 241.0	80	20	3 542.7	150	10	3 930.0	80	12
3 252.0	50	15	I 3 559.8	150	50	3 938.6	125	20
3 254.9	60	12	I 3 560.9	150R	100	3 939.6	50	12
3 256.9	80	12	3 562.3	50	20	3 949.8	50	10
3 260.3	60	10	3 569.8	100	30	3 960.5	50	15
I 3 262.3	500R	50	3 587.3	60	15	3 961.0	125	20
3 262.8	100	20	I 3 598.1	300	30	I 3 963.6	500	50
3 264.7	100	10	3 601.8	60	20	3 965.0	60	12
I 3 267.9p	400R	30	3 604.5	15	100	3 939.7	100	100
3 269.2	200	20	I 3 616.6	150	20	3 975.4	50	12
3 275.2	200	15	3 619.4	60	25	I 3 977.2	300	40
3 278.0	80	8	I 3 640.3	200	40	3 988.2	50	12
3 290.3	200	20	3 648.8	100	10	3 996.8	50	10
I 3 301.6p‡	500R	50	3 654.5	100	15	3 998.9	80	12
3 306.2	80	12	I 3 656.9	150	30	4 003.5	50	6
3 310.9	200	30	I 3 670.9	200	20	4 004.0	50	6
3 315.4	50	15	3 689.1	200	30	4 018.3	60	4
3 324.3	50	15	3 703.2	100	30	4 037.8	80	4
3 327.4	80	15	3 706.6	50	15	4 041.9	100	6
I 3 336.2	200R	50	3 712.8	50	12	4 066.7	100	100
3 351.7	50	12	3 713.7	100	20	4 074.7	80	6
3 358.0	100	15	I 3 719.5	40	12	4 088.4	100	3
3 361.1	80	20	I 3 720.1	80	40	4 091.8	100	12
3 364.1	100	12	3 732.9	200R	5	4 100.3	60	3
3 370.2	50	10	3 746.5	100	20	4 112.0	150	9
I 3 370.6	300R	30	I 3 752.5p	400R	100	4 129.0	60	3
3 378.7	50	10	3 766.3	100	20	4 135.8	200	50
3 384.0	80	5	3 768.1	80	15	4 137.8	100	3
I 3 387.8	100	15	3 774.4	60	15	4 158.8	50	1
3 391.3	2	5	3 774.6	60	12	4 172.6	60	3
I 3 401.9	200	20	3 776.3	50	15	4 173.2	100	6
I 3 402.5	200	15	3 777.0	150	20	4 175.6	100	4
3 427.7	80	15	I 3 782.2p	400R	200	4 189.9	60	3
3 444.5	50	12	I 3 790.1	80	30	4 195.1	100	1
3 445.6	80	15	3 790.7	100	20	4 202.1	100	4
3 449.2	100	20	I 3 793.9	125	300	4 211.9	150	50
3 455.0	50	15	3 800.4	50	15	I 4 260.9§	200	200
3 458.4	200	12	3 827.1	50	20	I 4 293.9	60	6
3 459.0	100	10	I 3 836.1	150	20	4 311.4	150	9
3 465.4	60	12	3 840.3	150	20	4 328.7	60	4
3 478.5	100	15	3 843.7	80	12	4 365.7	60	4
3 487.5	50	15	I 3 849.9	125	20	4 370.7	50	3
3 498.5	80	15	3 853.4	100	15	4 394.9	150	6

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

OSMIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
4 402.7	50	3	4 616.8	150	6	5 523.5	100	....
I 4 420.5‖	400R	100	4 631.8	100	5	5 584.4	50	....
4 436.3	80	3	4 663.8	100	5	5 721.9	80	....
4 447.4	200	3	4 692.1	80	3	5 780.8	50	....
4 479.8	80	1	4 743.9	60	....	5 800.6	50	....
4 484.8	100	1	4 794.0	300	6	5 857.8	80	....
4 488.6	60	....	4 816.0	60	....	5 996.0	50	....
4 524.9	80	2	4 865.6	80	1	6 227.7	30	....
4 529.7	80	2	4 899.2	60	....	6 403.1	15	....
4 537.6	50	....	4 912.6	80	....	6 729.6	30	....
4 539.9	100	2	5 039.1	50	....	7 060.7	15	....
4 548.7	100	5	5 149.7	80	....	7 145.5	30	....
4 550.4	150	10	5 376.8	50	....	7 148.9	15	....
4 551.3	150	8	5 416.3	80	....	7 253.5	15	....
4 595.0	80	4	5 416.7	50	....	7 602.9	20	....
4 597.2	100	4	5 443.3	50	....			

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Fe 2957.4	*Cd Cr Fe Mn Mo	V 3066.4	
Mo 2891.0		‡Pt 3042.6	‡Mo Na Pt Sr V Zn
V 2908.8		§Fe 4143.9	§Au Bi Co Cr Cu Fe
†Co 3044.0	†Al Au Fe Mo W	‖Fe 4315.1	‖Al Au Be Cd Co Cr Fe Mo Na Ni
Fe 3047.6		Mo 4426.7	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

PALLADIUM

Pd

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 045.6	....	100	II 2 609.9	....	200	II 3 267.4	....	200
II 2 212.1	5	50	II 2 613.4	....	100	II 3 272.6	....	60
II 2 296.5	20	60	II 2 628.3	....	200	I 3 287.2	300	25
II 2 302.0	....	60	II 2 635.9	50	300	I 3 302.1	1000	200
II 2 307.5	....	50	II 2 637.1	....	100	II 3 327.2	....	50
II 2 351.3	10	60	II 2 642.2	....	100	I 3 373.0	800R	500
2 368.0	10	60	II 2 649.5	....	200	I 3 380.7	150	2
II 2 372.2	5	50	II 2 657.6	....	200	I 3 404.6P†C	2000R	1000R
II 2 383.4	....	50	II 2 658.7p	20	300	I 3 421.2p‡C	2000R	1000R
II 2 385.0	....	50	II 2 661.1	....	100	I 3 433.4	1000	500
II 2 406.7	1	150	II 2 679.6	....	100	I 3 441.4	800	2
II 2 408.7	....	100	II 2 684.8	....	100	II 3 451.3	....	400
II 2 414.7	....	150	II 2 687.7	....	150	I 3 460.8	300R	600
II 2 418.7	....	50	II 2 688.6	....	200	II 3 468.5	....	50
II 2 424.5	....	100	II 2 698.5	....	200	I 3 481.2	500R	2
II 2 426.9	....	50	2 714.3	....	150	I 3 489.8	150	35
II 2 433.1	....	50	II 2 714.9	....	200	I 3 516.9p	1000R	500R
II 2 435.3	....	50	II 2 727.9	....	200	I 3 553.1	100R	15
II 2 446.2	....	100	II 2 742.6	....	100	3 566.6	60	....
II 2 446.7	....	50	II 2 763.1	300R	30R	I 3 571.2	40	40
I 2 447.9	200R	100	II 2 776.8	....	25	I 3 609.5p§C	1000R	700R
II 2 468.2	....	100	II 2 839.9	....	100	I 3 634.7p‖C	2000R	1000R
II 2 469.3	....	150	II 2 841.0	....	100	I 3 690.3	300	1000
II 2 470.0	....	150	II 2 854.6p	4	500	I 3 718.9	300	200
II 2 471.2	....	150	II 2 857.7	....	100	I 3 799.2	200	150
II 2 472.5	....	150	II 2 893.1	....	100	I 3 832.3	150	150
I 2 476.4	300R	50	I 2 922.5	200	25	I 3 894.2	200	200
II 2 486.5	5	30	II 2 954.4	....	60	I 3 958.6	500	200
II 2 488.9	10	30	II 2 980.7	....	200R	I 4 087.3	500	100
II 2 489.6p	....	75	II 2 999.6	....	100	I 4 140.8	100R	....
II 2 496.7	....	100	I 3 002.7	100R	60	I 4 169.8	200	50
II 2 498.8	4	150	I 3 009.8	50R	10	I 4 213.0	500	300
II 2 505.7	3	30	II 3 018.5	....	50	I 4 473.6	60	6
II 2 514.5	....	200	I 3 027.9	150	200	I 4 788.2	200	4
II 2 534.6	....	100	II 3 032.2	2	100	4 817.5	40	8
II 2 537.2	....	100	II 3 050.1	....	100	I 5 110.8	100	2
II 2 538.0	....	100	II 3 052.2	....	150	I 5 117.0	50	4
II 2 539.4	....	50	II 3 059.4	....	150	I 5 163.8	300	8
II 2 544.8	....	200	I 3 065.3	10	100	I 5 234.9	50	2
II 2 551.2	....	35	I 3 066.1	150	2	I 5 295.6	200	10
II 2 565.5	2	200	I 3 114.0	400	500	I 5 395.2	50	2
II 2 575.5	....	100	I 3 142.8	300	100	I 5 542.8	100	....
II 2 576.4	....	100	II 3 161.9	....	100	I 5 547.0	50	2
II 2 577.1	3	150	II 3 210.4	....	60	I 5 619.4	50	2
II 2 583.8	....	200	I 3 219.0	300	8	I 5 670.1	100	....
II 2 584.1	....	75	I 3 242.7*	2000	600R	I 5 695.1	50	....
I 2 593.3	3	100	II 3 243.1C	....	60	6 130.6	10	....
II 2 596.0	3	150	I 3 251.6	200	500	I 6 774.5	15	....
II 2 602.8	20	200	I 3 258.8	300	200	I 6 784.5	12	2

For explanation of control and interfering line symbols see page 445.

TABLE VI *(Continued)*

Principal Lines by Elements

PALLADIUM *(Continued)*

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 6 833.4	10	....	I 7 368.1	20	....	I 7 915.8	10	....
I 6 916.5	10	....	I 7 764.0	25	....			

Control lines:	Interfering lines:
*Ti 3239.0	*Cu Mn Ni Sb
†Cd 3466.2	†Bi Cd Co Cu Fe
Co 3453.5	
‡Co 3409.2	‡Ba Co Cr Mo
Cr 3408.8	

Control lines:	Interfering lines:
§Cd 2288.0	§Ba Cd Co Cu Cr
Cr 3593.5	
Fe 3618.8	
‖Fe 3570.1	‖Au Co Cr Fe Mo
Mo 3614.3	

PHOSPHORUS

P

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 023.5	15	....	2 895.3	....	25	4 385.3	....	100
I 2 024.6	12	....	II 3 175.1	....	70	4 422.2	300	....
I 2 033.5	15	....	3 219.3	....	100	4 446.9	70	....
I 2 136.2p	15	....	3 233.6	....	20	4 479.7	....	70
I 2 149.1p	15	....	3 364.4	....	100	II 4 587.9	....	300
I 2 154.1	15	....	3 371.1	....	70	II 4 602.0	....	300
I 2 534.0‡C	50	....	II 3 424.9	....	100	II 4 943.4	....	150
I 2 535.7*LC	100	....	II 3 556.5	....	100	5 253.5	....	300
I 2 553.3C	80	....	II 3 706.1	....	150	II 5 296.1	....	300
I 2 554.9C	60	....	II 3 827.4	....	150	II 5 425.9	....	150
2 739.3	....	25	4 178.4	....	300	II 5 499.7	....	150
2 883.9	....	25						

Control lines:	Interfering lines:
*Ag 2660.4	*Ag Co Fe Hg Mn Ti Pt Ni Ta Ag
Co 2432.2	
Fe 2539.0	
Fe 2538.8	

Control lines:	Interfering lines:
†Ag 2480.4	†Ag Cd Co Fe Ni Ta W Cr
Ag 2564.4	‡Ir Ta V Ti W Cb Fe
Mn 2551.9	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

PLATINUM

Pt

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 165.2	1000R	25	I 2 677.1	800	200	I 3 200.7	100	40
2 180.3	150	15	II 2 679.1	6	50	I 3 204.0	250	100
II 2 288.2	15	30	I 2 698.4	500	50	I 3 230.3	100	6
I 2 292.4	400	100	I 2 702.4†	1000	300	I 3 252.0	100	1
II 2 311.0	15	25	I 2 705.9C	1000	200	I 3 290.2	150	10
I 2 357.1	30	20	2 713.1	200	10	I 3 301.9	300	250
I 2 401.9	300	30	I 2 719.0	1000	1000	I 3 315.0	200	10
I 2 403.1	400	50	I 2 729.9	500	50	I 3 323.8	150	10
II 2 405.7	....	100	I 2 733.9‡	1000	200	I 3 343.9	100	80
II 2 410.3	....	50	I 2 734.5C	100	10	I 3 408.1	250	60
I 2 413.0	60	10	I 2 738.5	100	5	I 3 427.9	50	6
I 2 418.1	300	50	I 2 753.8	100	4	3 483.4	70	10
II 2 424.9	50	100	I 2 754.9	200	5	I 3 485.3	150	200R
I 2 428.0	100	10	I 2 769.8	50	2	I 3 628.1	300	20
I 2 428.2	100	20	I 2 771.6	500	15	I 3 638.8	250	10
I 2 429.1	100	....	I 2 773.2	50	5	I 3 643.2	60	8
I 2 436.7	300	20	I 2 773.9	50	5	I 3 663.1	50	2
I 2 440.1	800	100	II 2 774.8	10	100	I 3 672.0	80	10
II 2 450.4	25	50	I 2 793.3	100	5	I 3 674.0	80	4
I 2 451.0	400	10	II 2 794.2	10	100	I 3 699.9	80	5
2 467.4	800R	100	II 2 800.0	20	80	I 3 923.0	100	20R
II 2 467.6	5	100	I 2 803.2	400	5	I 3 925.3	60	3
I 2 471.0	100	20	2 818.2	70	4	I 3 948.4	60	5
I 2 487.2	600R	20	II 2 822.3	10	60	I 3 966.4	80	40
I 2 490.1	300	20	I 2 830.3pC	1000R	600R	I 3 996.6	50	....
I 2 498.5	400	50	I 2 834.7	80	5	I 4 118.7	400	10
I 2 504.0	60	5	II 2 860.7	30	150	I 4 164.6	100	80
2 505.9	150	10	II 2 865.1	20	80	I 4 192.4	100	2
I 2 508.5	300	20	II 2 875.8	20	80	I 4 288.1	75	1
II 2 513.9	6	50	II 2 877.5	40	200	I 4 327.1	80	4
I 2 514.9	150	10	I 2 888.2	50	....	I 4 391.8	50	3
I 2 515.0	150	20	I 2 893.9	500	25	I 4 442.6	800	25
I 2 515.6	500	20	I 2 897.9	400	15	I 4 498.8	100	5
I 2 529.4	80	....	I 2 905.9	100	15	I 4 520.9	40	2
I 2 536.4	100	10	I 2 912.3	300	25	I 4 552.4	60	10
I 2 539.2	400	20	I 2 913.5	300	25	5 044.0	60	1
I 2 549.4	80	10	I 2 919.3	150	40	5 059.5	60	3
I 2 552.2	150	20	I 2 921.4	100	6	5 227.7	80	2
2 596.0	200	20	I 2 929.8p§C	800R	200	5 301.0	150	10
I 2 603.1	300	20	I 2 998.0p‖C	1000R	200R	5 369.0	50	1
II 2 616.8	10	60	II 3 001.2	3	50	5 390.8	50	2
I 2 619.5	300	5	I 3 002.3	200	30	5 475.8	60	2
II 2 625.3	35	60	3 017.9	60	10	5 478.5	50	2
I 2 628.0	1000	100	I 3 036.5	200	10	5 840.1	80	....
I 2 639.3	500	50	I 3 042.6C	200R	250R	6 326.6	50	....
I 2 646.8	1000	100	I 3 064.7PC	2000R	300R	6 523.5	80	....
I 2 650.8C	700	100	I 3 071.9	60	15	6 710.4	50	....
I 2 658.2	100	10	I 3 139.4	300	80	6 760.0	100	....
I 2 659.4p*C	2000R	500R	3 141.8	150	5	6 842.6	10	....
2 674.5	200	10	I 3 156.6	150	50	I 7 113.7	80	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

PLATINUM (*Continued*)

Control lines:	Interfering lines:
*Al 3082.2	*Al Cr Ga Mg Mn Ta V Fe
Cr 2663.4	
Sn 2546.5	
†Mn 2610.2	†Ba Co Cr Fe Hg
Mo 2688.0	
‡Fe 2733.6	‡Cd Fe Mg Mn Mo
Mo 2717.3	
§Fe 2957.4	§Ag Cr Fe Mg Mo W Ir Mn Co Rh

Control lines:	Interfering lines:
In 3258.6	
Mg 2936.5	
‖Cr 3024.4	‖Co Cu Cr Mn Mo
Fe 2994.4	
Ni 3050.8	
¶Co 3044.0	¶Al Bi Co Cu Mo Ni W Cr Sc Ir Na
Fe 3057.5	
Ti 3078.6	

POTASSIUM

K

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 077.9	....	80	II 3 529.5	....	10	II 4 608.4	....	40
II 2 190.0	....	40	II 3 618.4	....	20	II 5 005.3	....	15
2 240.9	....	40	II 3 681.5	....	30	I 5 099.2	25	....
II 2 550.0	....	20	II 3 897.9	....	60	I 5 112.2	30	....
I 2 992.2	15R	....	II 4 001.2	....	40	I 5 323.2	40	...
I 3 034.8	30	....	I 4 044.1P*FC	800	400	I 5 339.7	40	....
II 3 062.2	....	20	I 4 047.2P†FC	400	200	I 5 343.0	30	....
I 3 102.0	50R	....	II 4 134.7	....	40	I 5 359.5	40	....
I 3 102.3	20R	....	II 4 149.2	....	20	I 5 782.6	60	....
I 3 217.0	100R	20	II 4 186.2	....	60	I 5 802.0	50	20
I 3 217.5	50R	25	II 4 223.0	....	40	I 5 812.5	30	....
3 345.3	....	30	II 4 225.6	....	40	I 5 832.1	50	....
II 3 380.6	....	30	II 4 263.3	....	40	6 911.3	300	....
II 3 384.9	....	30	II 4 309.1	....	40	I 6 939.0	500	....
II 3 440.0	....	40	II 4 388.1	....	40	I 7 664.9PC	9000R	400
I 3 446.4	150R	100R	II 4 466.7	....	20	I 7 699.0PC	5000R	200
I 3 447.4	100R	75R	II 4 505.3	....	30			

Control lines:	Interfering lines:
*Co 4092.4	*Co Cr Cu Fe Hg Ni Sc Ti W U Ca Zr
Fe 4271.8	
Hg 4358.3	
Mn 4034.5	

Control lines:	Interfering lines:
†Co 4092.4	†Co Cr Fe Hg Mn Pt Sc Te Ti W Ce Ca U Y
Fe 4271.8	
Hg 4358.3	
Mn 4055.6	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

PRASEODYMIUM

Pr

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 297 8	....	100	3 889.3	150	70	4 118.5	250	50
2 488 7	....	30	3 902.5	60	40	4 141.3	150	50
2 980.5	....	25	3 908.0	100	50	4 143.1	200	50
2 985.8	....	25	3 908.4	100	60	4 164.2	200	50
3 121.6	50	4	3 912.9	150	80	4 171.8	75	40
3 631.0	50	20	3 913.6	80	30	4 172.3	75	40
3 641.6	50	5	3 918.9	100	30	4 179.4p	200	40
3 646 3	50	15	3 924.1	100	15	4 189.5	100	50
3 668.8	100	40	3 925.5	125	100	4 206.7	50	50
3 685.3	60	8	3 927.5	80	35	4 211.9	50	25
3 687.0	60	20	3 935.8	125	50	4 223.0	125	40
3 687.2	50	15	3 937.0	50	8	4 225.3p	50	40
3 714.1	50	20	3 940.2	80	15	4 241.0	50	12
3 739.2	80	30	3 947.6	125	60	4 247.7	60	35
3 761.9	150	100	3 949.4	150	100	4 263.8	50	5
3 764.8	100	50	3 953.5	150	100	4 272.3	50	35
3 768.9	50	30	3 960.6	50	25	4 280.1	60	30
3 772.9	80	20	3 962.4	60	50	4 282.4	75	40
3 774.1	100	50	3 964.3	60	50	4 297.8	50	40
3 781.6	100	50	3 964.8	125	80	4 302.1	60	5
3 783 9	100	30	3 965.3	100	50	4 303.6	100	60
3 785.5	50	20	3 966.6	100	70	4 305.8	150	90
3 788.9	50	25	3 971.2	100	60	4 311.1	50	10
3 792.5	100	8	3 971.7	60	40	4 316.1	50	8
3 794.4	50	25	3 972.2	125	80	4 323.6	100	35
3 799.7	50	25	3 976.3	50	10	4 328.4	50	15
3 800.3	100	50	3 982.1	125	100	4 329.0	50	10
3 803.1	50	20	3 989.7	200	125	4 329.4	50	20
3 804.9	25	50	3 994.8	300	25	4 330.4	50	3
3 809.2	80	40	3 997.1	100	40	4 333.9	150	100
3 816.2	40	40	3 999.2	50	40	4 335.7	80	20
3 818.3	125	100	4 000.2	50	25	4 338.7	100	50
3 821.8	50	50	4 008.7	150	50	4 344.3	150	80
3 823.2	125	25	4 015.4	50	30	4 347.5	100	40
3 826.3	80	50	4 031.8	50	30	4 350.4	70	25
3 830.7	100	60	4 033.9	50	35	4 351.8	80	60
3 842.4	80	40	4 039.4	50	20	4 354.9	80	30
3 844.6	50	10	4 044.8	50	35	4 359.1	70	25
3 846.6	70	30	4 051.2	50	30	4 359.8	100	40
3 850.8	50	15	4 054.8	50	40	4 363.0	50	20
3 851.6	200	150	4 056.5	100	60	4 368.3	125	90
3 852.8	100	50	4 062.8p	150	50	4 371.6	125	40
3 854.9	80	30	4 079.8	50	35	4 374.4	50	15
3 865.5	200R	125R	4 081.0	50	25	4 379.3	100	2
3 876.2	80	30	4 081.9	75	30	4 380.3	50	20
3 877.2	125	80	4 087.2	50	3	4 396.1	80	50
3 879 2	100	80	4 095.0	50	12	4 403.6	100	40
3 880.5	80	60	4 100.7	200	50	4 405.8	100	100
3 885.2	100	40	4 113.9	30	70	4 408.8	125	100

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

PRASEODYMIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
4 412.2	50	15	4 684.9	125	10	5 027.0	80	1
4 413.8	90	40	4 687.8	50	1	5 110.4	80	2
4 419.1	80	30	4 695.8	60	2	5 110.8	80	3
4 419.7	100	50	4 707.5	80	10	5 129.5	100	....
4 421.2	100	35	4 707.9	50	10	5 133.4	60	1
4 424.6	90	35	4 708.2	50	10	5 135.1	60	2
4 429.2	200	125	4 730.7	60	1	5 173.9	100	4
4 432.3	80	10	4 734.2	100	8	5 219.1	50	2
4 438.2	50	20	4 736.7	125	1	5 220.1	80	3
4 447.0	50	30	4 744.2	80	....	5 259.7	125	3
4 449.9	125	80	4 744.9	100	10	5 292.1	60	....
4 451.9	80	20	4 746.9	100	25	5 292.6	50	2
4 454.4	60	15	4 756.0	50	2	5 322.8	30	3
4 458.3	90	10	4 756.1	50	2	5 352.4	80	2
4 466.0	90	30	4 757.9	100	5	5 381.3	60	2
4 468.7	125	100	4 762.7	60	10	5 509.1	50	2
4 477.3	125	30	4 765.2	80	5	5 668.5	25	....
4 496.4	200	125	4 783.4	125	10	5 707.6	100	....
4 510.2	200	125	4 823.0	125	10	5 779.3	50	....
4 534.2	150	80	4 832.1	100	....	5 823.7	60	1
4 535.9	125	100	4 837.0	80	....	6 017.8	40	2
4 548.5	60	30	4 848.5	125	....	6 055.1	100	....
4 552.3	60	....	4 877.8	50	5	6 161.2	50	2
4 563.1	100	40	4 907.0	50	....	6 165.9	50	2
4 576.3	50	15	4 914.0	60	....	6 281.3	25	1
4 612.1	60	15	4 924.6	80	....	6 359.0	40	....
4 628.8	200	50	4 936.0	50	....	6 566.7	20	....
4 639.6	60	2	4 939.7	100	....	6 656.8	30	....
4 643.5	60	5	4 940.3	50	....	6 673.8	40	....
4 646.1	50	8	4 951.4	150	....	6 747.2	20	....
4 651.5	125	40	4 989.3	50	....	6 798.7	20	....
4 664.6	100	15	5 018.6	50	1			
4 672.1	100	25	5 019.8	50	1			

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

RHENIUM

Re

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 023.7	10	50	2 670.8	50	....	I 3 129.0	100	....
2 092.5	18	50	2 671.8	60	....	I 3 151.6	150	....
2 109.3	50	8	I 2 674.3	100	....	I 3 153.8	80	....
2 214.3	100	100	2 683.6	50	....	I 3 158.3	200	....
2 226.5	60	12	2 688.5	100	....	I 3 158.4	150	....
2 275.3	300R	300R	2 690.3	50	....	3 177.7	80	....
2 405.1	100	....	I 2 697.3	50	....	I 3 182.9	100	....
2 405.6	80	....	I 2 715.5	100	....	I 3 184.8	150	....
2 421.8	50	....	I 2 722.7	50	....	I 3 185.6	200	....
2 431.5	50	....	2 758.0	60	....	I 3 194.5	50	....
2 432.2	100	....	2 763.8	50	....	I 3 200.0	50	....
2 447.0	100	....	2 766.4	50	....	3 204.2	30	....
2 461.2	125	....	I 2 770.4	60	....	3 212.9	50	....
2 461.9	80	....	I 2 783.6	150	....	3 235.9	50	....
2 483.9	150	....	2 791.3	60	....	I 3 258.9	100	....
2 485.8	50	....	2 807.9	50	....	3 259.5	100	....
2 486.8	50	....	2 814.7	50	....	3 261.6	50	....
2 487.2	50	....	I 2 820.0	150	....	I 3 296.7	80	....
2 501.7	80	....	2 834.1	100R	....	I 3 297.0	60	....
2 502.4	60	....	I 2 871.8	50	....	I 3 301.6	50	....
2 504.6	80	....	I 2 875.3	80	....	I 3 322.5	150	....
2 509.0	125	....	2 883.5	60	....	I 3 335.4	100	....
2 516.1	125	....	I 2 887.7	125	....	I 3 338.2	150	....
2 520.0	50	....	I 2 896.0	125	....	I 3 342.3	200	....
2 521.6	100R	....	I 2 902.5	125	....	I 3 344.3	150	....
2 534.8	100	....	I 2 905.6	50	....	I 3 346.2	100	....
2 545.0	60	....	2 927.4	125	....	3 355.3	60	....
2 552.0	80	....	2 930.6	50	....	3 379.0	50	....
2 556.5	100	....	I 2 943.1	60	....	I 3 379.7	80	....
2 558.1	60	....	I 2 965.1	100	....	I 3 399.3	200	....
2 564.2	50	....	I 2 965.8	150	....	I 3 404.7	100	....
2 573.8	60	....	I 2 976.3	50	....	I 3 405.9	150	....
2 586.8	100	....	I 2 992.4	100	....	3 408.7	100	....
2 592.9	50	....	I 2 999.6	125	....	I 3 419.4	80	....
2 595.2	60	....	I 3 016.0	80	....	I 3 424.6	300	....
2 599.9	80	....	3 016.5	100	....	I 3 427.6	50	....
2 603.9	100	....	I 3 030.5	100	....	I 3 437.7	100	....
2 614.6	60	....	I 3 058.8	50	....	3 449.4	100R	....
2 620.0	60	....	I 3 067.4	60	....	I 3 451.8	100	....
2 620.4	50	....	3 069.9	125	....	I 3 460.5	1000	....
2 623 3	50	....	3 071.2	50	....	I 3 464.7	100	....
2 631 6	80	....	I 3 082.4	100	....	I 3 468.0	100	....
2 636.6	125	....	3 088.8	60	....	I 3 480.4	50	....
2 642.8	125	....	I 3 093.7	60	....	I 3 480.9	50	....
2 647.1	100	....	I 3 100.7	100	....	I 3 503.1	80	....
2 649.1	100	....	I 3 108.8	125	....	I 3 512.3	50	....
2 651 9	100	....	I 3 110.9	100	....	3 516.6	60	....
2 654 1	50	....	3 118.2	200	....	3 517.3	50	....
2 663.6	150	....	I 3 121.4	100	....	I 3 537.5	80	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

RHENIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 3 558.9	50	....	4 391.3	60	....	5 815.9	50	....
I 3 579.1	50	....	4 392.5	100	....	5 834.3	200	....
3 580.1	80	....	4 394.4	100R	....	5 943.2	100	....
I 3 583.0	100	....	4 406.4	60	....	6 145.8	50	....
I 3 617.1	50	....	4 454.7	100	....	I 6 146.8	50	....
I 3 637.8	50	....	4 467.9	50	....	I 6 243.2	50	....
I 3 643.0	100	....	4 513.3	300	....	I 6 307.7	100	....
I 3 689.5	100	....	4 516.6	80	....	I 6 321.9	100	....
I 3 691.5	100	....	4 522.7	100	....	I 6 350.8	100R	....
3 697.7	150	....	4 605.7	50	....	I 6 511.5	60	....
I 3 717.3	150	....	4 614.7	50	....	I 6 577.2	50	....
I 3 740.1	50	....	4 630.8	50	....	I 6 592.5	60	....
I 3 787.5	80	....	4 648.4	50	....	I 6 605.2	100	....
I 3 796.6	60	....	4 691.4	200	....	6 652.4	80	....
I 3 834.2	50	....	I 4 889.2	2000	....	6 751.2	50	....
I 3 843.5	50	....	4 923.9	150	....	6 752.0	50	....
I 3 876.9	60	....	4 946.7	100	....	6 813.4	200	....
I 3 917.3	100	....	5 096.5	100	....	I 6 830.0	200	....
I 3 929.8	100	....	5 104.6	50	....	I 6 971.5	150	....
I 3 962.5	100	....	5 126.7	50	....	I 7 006.7	100	....
I 4 029.6	80	....	5 178.9	100	....	I 7 024.1	125	....
I 4 121.6	50	....	5 271.0	200	....	I 7 246.7	300	....
I 4 133.4	200	....	5 275.5	500	....	I 7 273.8	150	....
I 4 136.4	150	....	5 278.2	100	....	7 292.7	300	....
I 4 144.4	125	....	5 327.5	100	....	7 352.0	50	....
I 4 182.0	150R	....	5 331.9	80	....	I 7 578.7	200	....
I 4 221.1	100	....	5 377.0	300	....	I 7 611.9	100	....
I 4 227.5	200	....	5 532.7	100	....	I 7 620.3	200	....
I 4 257.6	125	....	5 563.2	150	....	I 7 640.9	400	....
4 291.2	100	....	5 567.9	100	....	I 7 869.6	100	....
I 4 332.3	50	....	5 740.3	50	....	I 7 912.9	400	....
I 4 358.7	80	....	5 753.0	200	....	I 7 980.8	300	....
4 367.6	80	....	5 776.8	300	....			

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

RHODIUM

Rh

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 017.5	....	80	2 383.4	50	10	I 2 555.4	100	60
2 023.7	....	70	2 386.1	80	8	2 581.7	1	150
2 040.2	2	100	2 390.6	10	50	2 587.3	2	100
2 048.7	....	200	2 396.6	2	200	2 597.1	3	150
2 051.3	2	100	2 405.2	1	50	2 603.3	....	100
2 076.8	....	100	I 2 407.9	60	5	2 609.2	3	200
2 085.6	....	100	2 410.7	2	50	I 2 622.6	50	25
2 091.1	....	100	2 411.9	2	50	2 625.4	2	200
2 097.8	3	200	2 415.8	100	200	I 2 625.9	60	25
2 099.0	15	300	2 421.0	30	100	2 628.1	1	150
2 100.5	2	100	2 427.3	2	50	2 630.3	2	50
2 102.5	....	50	2 438.9	2	100	2 638.7	2	100
2 104.9	....	100	2 443.7	4	100	2 639.3	2	100
2 111.7	....	150	2 444.1	2	100	I 2 652.7	100	25
2 112.7	3	80	I 2 444.3	100	30	2 657.3	....	70
2 113.7	....	70	2 447.9	4	200	2 659.1	....	100
2 116.9	3	50	2 448.3	2	100	2 674.4	1	200
2 118.5	2	200	2 455.7	15	200	2 676.3	1	100
2 139.4	....	100	2 456.2	5	150	I 2 680.6	60	10
2 200.0	....	50	2 458.9	50	300	2 681.6	....	100
2 205.0	....	100	2 461.0	80	200	2 683.6	1	200
2 206.4	....	80	2 466.1	1	100	2 684.2	2	150
2 226.5	50	....	2 467.2	....	50	2 689.6	1	100
2 237.7	....	100	I 2 470.4	70	5	2 691.1	1	60
2 261.8	2	100	I 2 471.5	70	8	2 700.6	2	80
2 263.4	5	200	2 471.8	3	100	I 2 703.7	150	25
2 264.1	50	25	2 482.7	2	100	2 705.6	100	300
2 277.0	20	150	I 2 483.3	100R	5	I 2 707.2	100	4
2 284.1	....	200	2 485.8	2	50	I 2 709.5	50	2
2 290.0	25	500	2 487.5	100	8	I 2 714.4	150	5
2 294.1	1	50	2 490.8	100	100	I 2 715.0	50	2
2 295.1	5	50	2 491.9	2	400	2 715.3	50	500
2 298.3	....	150	I 2 492.3	100	10	I 2 716.8	50	3
2 306.0	....	100	2 496.0	2	50	I 2 717.5	150	20
2 312.7	2	100	2 501.2	50R	50	2 718.0	....	50
2 321.9	....	80	2 503.8	2	150	I 2 718.5	150	20
2 322.6	50	10	2 505.1	2	200	2 720.1	100	6
I 2 333.3	8	125	I 2 509.7	40	20	I 2 720.5	50	2
2 334.8	25	500	2 510.7S_2G_2	5	200	I 2 729.0	200	200
2 336.8	1	125	I 2 515.7	60	10	I 2 736.8	100	3
2 346.4	2	100	2 517.5	....	150	2 737.4	30	400
2 349.7	3	125	2 520.5S_3G_3	10	1000	2 739.9	10	300
2 350.4	....	50	2 534.6	2	100	2 747.6	1	100
2 357.4	2	50	2 537.0	15	100	I 2 752.8	50	2
2 359.2	15	100	2 537.7	4	50	2 761.3	1	50
2 359.6	....	50	2 542.2	1	50	2 764.8	15R	125
2 368.3	50	2	2 543.9	15	100R	2 766.5	5	150
2 377.8	....	50	2 545.4	8	150	I 2 767.7	100	4
2 382.9	50	5	2 545.7	50	10	2 768.2	50	4

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

RHODIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 771.5	100	8	I 3 214.3	70	20	I 3 543.9	150	40
2 775.8	5	125	I 3 217.9	60	20	I 3 549.5	150	50
I 2 778.1	100	3	I 3 218.3	60	....	I 3 570.2	400R	150
2 778.2	2	100	I 3 237.7	60	20	I 3 583.1F	200	125
I 2 779.5	100	6	I 3 263.1	200	40	I 3 596.2FS_4G_4	200	50
2 781.8	1	150	I 3 271.6	200	60	I 3 597.1S_5G_5	200	100
I 2 783.0	150	10	I 3 280.5	30R	10	I 3 612.5	200	50
I 2 791.2	100	1	I 3 283.6	150	....	I 3 626.6	150	60
I 2 796.6	100	1	I 3 289.1	150	50	I 3 639.5	125	70
I 2 826.7	100	50	3 289.6	50R	5	I 3 658.0‖S_6G_6	500	200
I 2 827.3	50	....	I 3 294.3	60	25	I 3 666.2	70	30
I 2 834.1	70	30	I 3 300.5	100	20	I 3 690.7F	125	50
I 2 836.7	60	....	I 3 323.1pF	1000	200	I 3 692.4p¶	500	150
I 2 856.2	60	30	I 3 331.1	50	10	3 695.5F	15	10
I 2 862.9	150	60	I 3 338.5	200	50	I 3 700.9	150	150
2 864.4	70	10	I 3 344.2	100	20	I 3 713.0	100	100R
2 871.4	100	10	I 3 359.9	100	50	I 3 735.3	70	2
2 873.6	60	10	I 3 362.2	100	20	I 3 737.1	50	1
I 2 878.7	50	10	I 3 368.4	300	50	3 737.3	50	10
I 2 889.1	80	1	I 3 372.3	300	200	I 3 748.2	200	100
I 2 889.8	70	30	I 3 396.9p*CF	1000	500	I 3 765.1	100	70
I 2 900.0	70	30	I 3 399.7	500	60	3 788.5	50	25
I 2 907.2	100	30	I 3 406.5	50	8	I 3 793.2	200	60
2 910.2	50	12	3 412.3	300	60	I 3 799.3	25	100
I 2 912.6	50	20	3 434.9p†FC	1000R	200R	I 3 805.9	25	50
I 2 915.4	80	40	3 440.5	2	100	I 3 806.8	50	50
I 2 924.0	100	....	I 3 447.7	50	5	I 3 818.2	50	25
2 929.1	100	10	I 3 450.3	100	10	I 3 822.3	100	100
I 2 931.9	80	20	3 451.1	50	2	I 3 828.5	100	60
I 2 968.7	125	30	I 3 455.2	300	12	I 3 833.9	25	50
I 2 977.7	125	30	I 3 455.4	50	2	I 3 856.5S_7G_7	50	20
I 2 986.2	150	60	I 3 457.1	100	4	I 3 872.4	50	3
I 2 987.0	80	20	I 3 457.9	125	10	I 3 934.2	100	2
I 3 023.9	100	2	I 3 462.0	1000	150	I 3 942.7S_8G_8	60	25
I 3 028.4	80	....	I 3 469.6	100	10	I 3 958.9	200	100
3 067.3	80	1	I 3 470.7	500	125	I 4 082.8	100	50
I 3 084.0	150	2	I 3 472.3	100	8	I 4 119.7	100	25
I 3 114.9	100	2	I 3 474.8	700	125	I 4 121.7	150	50
I 3 121.8	150	....	I 3 478.9	500	100	I 4 128.9	300	150
I 3 123.7	150	2	I 3 494.4	50	3	I 4 135.3	300	150
I 3 130.8	60	2	I 3 498.7	500	60	4 154.4	60	1
I 3 137.7	100	....	I 3 502.5‡	1000	150	I 4 196.5	100	50
3 151.4	80	2	I 3 507.3	500	125	I 4 211.1	15	200
3 152.6	80	3	I 3 511.8	50	3	I 4 288.7	400	100
3 155.8	150	2	I 3 513.1	50	3	I 4 373.0	60	10
I 3 179.7	50	....	I 3 525.7	50	2	I 4 374.8**C	1000	500
I 3 185.6	100	20	I 3 527.0	1000	150	I 4 379.9	60	25
I 3 189.1	100	20	I 3 528.0§F	1000	150	4 492.5SF	30	8
I 3 191.2	300	50	I 3 538.1	100	10	I 4 528.7	500R	60
I 3 194.6	50	10	I 3 538.3	50	4	I 4 569.0	100	25
I 3 197.1	50	10	I 3 541.9	50	10	I 4 675.0	100	50

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

RHODIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 4 842.4	50	....	I 5 390.4	125	3	I 6 752.4	150	....
4 844.0	100	60	5 404.7	50	1	6 965.7	200	....
4 851.6	80	30	5 424.1	100	2	I 7 101.6	60	....
I 4 963.7	100	....	5 535.0	80	1	I 7 104.5	80	....
I 5 090.6	150	1	I 5 544.6	50	1	I 7 268.2	125	....
I 5 155.5	150	1	I 5 599.4	300	3	I 7 270.8	200	....
5 158.7	80	1	I 5 686.4	100	1	I 7 271.9	80	....
5 176.0	200	1	I 5 806.9	100	1	I 7 442.4	100	....
I 5 184.2	100	1	I 5 831.6	80	1	I 7 475.7	100	....
5 193.1	200	3	I 5 983.6	200	2	I 7 495.2	100	....
I 5 237.2	100	2	6 102.7	100	....	I 7 772.9	100	....
I 5 269.3	50	1	I 6 319.5	50	....	I 7 791.6	100	....
I 5 292.1	80	1	I 6 414.7	50	....	7 824.9	200	....
I 5 354.4	300	5	I 6 519.7	40	....	I 7 830.0	80	....
I 5 379.1	100	3	I 6 630.2	40	....	I 7 846.5	50	....
5 381.5	100	....						

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Bi 2993.3	*Bi Cu Fe Hg Mo Ce U V Zr	Mn 3548.0	
Co 3409.2		‖Mo 3680.7	‖Co Fe Hg Mn Mo
†Co 3443.6	†Cr Cu Mo Hg Ni U Ce Ti Mo Ir Ag	Ti 3234.4	
Ni 3393.0		¶Fe 3709.3	¶Co Hg Mn Mo Pb
‡Ba 4166.0	‡Ag Ba Co Cr Mo	Mo 3680.7	
Co 3405.1		V 3828.6	
Fe 3558.5		**Cr 4337.6	**Al Bi Cd Co Cr Cu Mo Sc Ti
§Co 3506.3	§Au Co Cu Fe Ni	Mo 4377.8	
Fe 3558.5		Mo 4369.1	

Control lines:
S_2Pt 2514.0
2488.0
2482.2
S_3Pt 2514.0
2488.7
2482.2
S_4Pt 3638.8
S_5Pt 3638.8
S_6Pt 3638.8

Control lines:
3706.5
S_7Pt 3925.3
3923.0
S_8Pt 3948.4
S_9Pt 3925.3
3923.0
G_2Pt 2513.9
2488.7
2482.1

Control lines:
G_3Pt 2513.9
2488.7
2482.1
G_4Pt 3638.8
G_5Pt 3597.2
G_6Pt 3638.8
3706.7
G_7Pt 3923.0
G_8Pt 3948.4
G_9Pt 3923.0
3948.4

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

RUTHENIUM

Ru

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 238.3	50	....	2 476.9	60	2	2 576.1	....	50
2 241.1	60	....	2 478.9	80	60	2 579.0	12	80
2 253.6	50	....	I 2 481.1	12	80	2 580.8	50	3
2 255.5	80	3	2 489.9	60	....	2 581.1	60	2
2 272.1	100	3	2 493.7	20	80	2 584.1	50	3
2 278.2	80	....	2 494.0	80	....	2 585.7	50	....
2 279.6	100	10	2 494.5	50	60	2 589.4	....	60
2 285.4	80	1	2 495.7	80	35	2 589.6	60	3
2 287.7	60	1	2 497.7	50	1	2 591.0	12	100
I 2 291.2	60	1	2 498.4	60	40	2 591.1	50	....
2 299.3	50	....	2 498.6	60	40	2 592.0	60	6
2 300.4	50	....	2 499.8	50	4	2 592.2	....	80
2 302.5	80	3	2 501.5	60	1	2 594.9	60	4
2 320.7	50	....	2 507.0	60	8	2 595.8	....	100
2 322.0	60	2	I 2 508.3	50	2	2 597.1	....	50
2 340.7	60	4	2 508.7	....	50	2 598.8	4	50
2 342.7	60	10	2 509.1	50	20	2 602.2	....	100
2 342.8	60	40	2 512.8	80	2	2 604.1	....	80
2 348.3	50	....	2 513.3	50	80	2 605.3	50	4
2 349.3	60	4	2 515.3	60	2	I 2 609.1	80	12
2 351.3	60	4	2 517.3	60	80	2 610.1	....	60
2 357.9	60	100	2 517.6	50	....	2 611.0	50	5
2 370.2	60	....	2 518.4	3	50	2 611.5	3	80
2 375.3	80	5	2 519.2	20	80	2 612.1	100	30
2 375.6	50	80	2 521.6	60	1	2 612.5	....	80
2 382.0	50	150	2 524.9	10	80	2 614.1	60	3
2 387.9	60	3	2 525.2	30	....	2 614.6	50	4
2 392.4	80	6	2 526.8	50	20	2 615.1	60	100
2 393.3	80	1	2 528.0	....	60	2 616.8	50	4
2 394.0	50	....	2 528.9	60	2	2 617.1	....	50
2 396.7	60	80	I 2 533.2	50	....	2 619.4	....	60
2 402.7	100	150R	2 534.0	4	80	2 619.7	50	5
2 407.9	60	50	2 535.6	....	100	2 620.6	50	5
2 420.8	60	2	2 539.7	12	100	2 623.8	50	....
2 422.6	50	1	2 540.3	10	100	2 626.2	50	....
2 422.9	60	8	2 541.3	50	....	2 626.4	20	50
2 429.6	60	....	2 543.3	50	150	2 626.5	50	....
2 432.9	60	....	2 544.2	60	6	2 627.7	60	1
2 434.9	50	....	2 547.7	5	80	2 628.7	....	100
2 454.9	60	5	2 549.6	50	3	2 630.0	....	50
2 455.5	80	100R	2 556.3	50	....	2 630.2	50	1
2 456.4	60	50	2 558.5	50	1	2 631.1	....	50
2 456.6	60	50	2 560.3	60	5	2 631.6	60	3
2 458.6	60	2	2 563.2	50	1	2 632.1	50	2
2 462.9	60	....	2 564.6	50	2	2 632.5	50	1
2 464.7	50	4	2 565.2	50	....	2 632.7	....	80
2 474 0	50	1	I 2 568.8	60	8	2 633.5	50	1
2 475.4	100	3	2 571.0	50	....	2 633.8	....	80
2 476.3	50	....	2 573.5	5	50	2 635.9	30	100

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

RUTHENIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 636.5	8	100	2 709.2	60	8	2 764.7	50	1
2 636.7	60	....	2 710.2	50	100	2 765.1	....	80
2 638.5	60	4	2 712.4p	80	300	2 765.4	50	150
2 639.1	60	5	2 713.1	....	80	2 765.9	....	50
2 639.9	50	....	2 713.2	60	2	2 766.5	....	100
2 640.3	60	5	2 713.6	....	100	2 768.9	60	200
2 641.6	....	100	2 713.7	60	2	2 770.3	60	3
2 642.8	....	150	2 715.8	50	....	2 770.7	60	....
I 2 643.0	150	....	2 716.1	....	100	2 771.1	....	100
2 644.6	8	100	2 716.6	....	80	2 772.5	....	150
2 646.0	20	150	2 717.4	50	100	2 772.6	50	....
2 647.3	50	5	2 717.9	....	50	2 774.5	60	2
2 648.8	30	150	I 2 719.5	100	30	2 775.2	50	....
2 650.4	50	....	2 719.7	12	50	2 775.6	50	150
I 2 651.3	60	5	I 2 721.7	60	5	I 2 775.9	50	....
2 651.8	100	9	I 2 722.7	60	1	2 777.4	....	50
2 653.9	....	80	2 723.1	....	50	2 777.5	5	50
2 656.2	20	150	2 724.1	60	4	2 778.4	....	150
2 657.2	....	50	2 724.9	....	100	2 779.0	50	50
I 2 659.6	80	12	2 725.5	80	200	I 2 782.2	50	1
2 661.2	20	100	2 727.0	60	10	2 784.5	60	100
2 661.6	80	150	2 728.8	60	....	I 2 785.7	60	200
2 661.9	50	....	2 729.5	60	....	2 787.8	60	150
I 2 664.8	60	5	I 2 730.3	60	2	2 788.7	....	50
2 667.4	10	150	I 2 730.9	80	5	2 792.3	10	100
2 667.8	....	80	2 731.9	50	....	2 792.6	50	1
2 668.0	50	....	2 733.6	80	4	2 799.9	....	50
2 669.4	....	100	2 734.3	80	200	2 802.8	50	150
2 673.0	8	50	2 735.7	60	60	2 803.5	50	4
2 673.5	50	3	2 736.5	12	80	2 804.9	....	60
2 673.6	50	3	2 736.8	30	60	2 806.7	50	100
2 674.2	....	50	2 737.6	....	50	2 808.2	50	....
2 675.5	....	50	2 737.8	....	60	I 2 810.0	50	12
2 676.2	8	100	2 738.9	60	2	I 2 810.6	50	200
2 676.4	50	3	I 2 739.2	60	5	2 813.3	....	75
2 678.8pL	100	300	2 742.3	4	50	2 813.7	50	125
2 680.5	5	50	2 743.9	50	100	I 2 817.1	50	4
I 2 686.3	80	12	2 744.5	30	50	I 2 818.4	50	12
2 687.5	12	100	2 745.2	12	15	I 2 819.0	50	3
2 688.1	8	100	2 745.8	50	80	2 821.4	5	100
2 689.9	50	....	2 746.1	50	8	2 822.0	50	5
2 692.1p	8	200	2 749.7	50	10	2 822.6	30	150
2 693.3	80	2	2 750.4	50	....	2 823.2	20	80
2 700.2	....	100	2 752.1	....	60	2 825.1	....	60
I 2 700.5	50	....	2 752.5	50	....	2 825.5	....	80
2 701.3	60	8	2 752.8	50	150	2 826.2	....	80
I 2 702.8	80	8	2 753.4	50	50	2 826.7	....	100
2 703.8	60	3	I 2 754.6	50	1	I 2 829.2	50	8
2 704.6	....	100	2 757.8	50	....	2 840.5	60	8
2 707.3	....	60	2 762.3	50	3	2 841.1	....	125
2 708.0	50	3	2 763.4	50	15	2 841.7	50	200

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENT

RUTHENIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 844.7	....	150	2 965.5p	60	200	3 068.3	60	8
2 848.6	50	3	2 969.0	60	6	I 3 073.3	50	5
2 849.3	3	100	2 974.0	50	5	3 073.5	10	80
I 2 854.1	60	35	2 976.6p	60	200	I 3 076.8	50	3
2 854.7	2	60	2 976.9	60	5	I 3 080.9	50	6
2 856.6	....	50	2 977.2	50	80	3 081.4	4	50
2 857.8	4	60	2 977.5	30	60	I 3 083.1	50	3
I 2 860.0	60	12	2 978.6	50	150	3 086.1	60	6
I 2 861.4	60	35	2 980.0	60	80	I 3 089.1	60	12
2 862.9	6	60	2 981.0	10	50	I 3 089.8	60	5
2 863.3	30	80	2 981.9	60	3	3 090.2	50	6
I 2 866.6	60	25	I 2 988.9	250	100	3 091.9	50	5
2 870.5	....	50	2 991.6	50	100	3 093.9	30	100
2 871.6	50	5	I 2 993.3	60	9	3 094.4	50	3
2 873.3	4	60	I 2 995.0	80	40	3 094.6	6	50
2 875.0	80	50	2 996.0	4	50	3 096.6	70	60
2 879.1	....	60	2 996.9	60	5	I 3 099.3	70	60
2 879.8	50	12	2 998.3	80	8	I 3 100.8	70	50
2 832.1	30	200	2 998.9	50	100	3 103.4	3	50
2 886.5	60	50	2 999.8	8	50	3 105.3	50	40
2 897.7	6	60	I 3 001.6	60	5	I 3 105.4	50	1
2 898.2	....	60	3 004.6	50	2	I 3 106.8	50	3
2 900.4	....	50	3 006.6	70	15	3 107.6	10	50
I 2 905.7	50	12	3 008.3	50	3	I 3 107.7	25	....
2 909.7	....	150	3 008.8	50	5	I 3 110.5	60	6
2 913.2	50	3	I 3 012.9	60	4	I 3 111.9	50	5
2 914.0	....	50	I 3 013.4	60	5	3 112.7	50	3
2 914.3	50	....	3 015.4	8	50	I 3 113.4	50	....
I 2 916.3	100	25	3 017.2	100	50	I 3 118.1	50	50
2 917.8	60	2	3 017.8	10	60	3 118.7	50	3
2 918.5	....	60	I 3 020.9	60	40	I 3 124.2	60	8
2 919.6	80	12	3 027.8	12	50	3 124.6	50	2
2 927.5	50	200	I 3 033.5	70	10	I 3 126.0	70	12
2 933.2	20	150	I 3 034.1	60	5	3 126.6	12	50
2 935.5	10	80	I 3 035.5	60	4	3 129.6	50	1
I 2 940.4	50	3	3 036.5	50	150	I 3 129.8	60	4
2 942.3	30	100	I 3 038.0	50	5	3 132.9	60	5
2 943.9	50	5	I 3 038.2	80	5	I 3 134.8	10	100
2 945.1	6	50	3 040.3	60	10	3 135.8	10	80
2 945.7p	60	300	3 042.5	70	12	3 136.6	60	6
I 2 947.0	60	12	I 3 042.8	60	5	3 140.5	50	....
I 2 949.5	80	12	I 3 045.7	60	12	I 3 141.0	60	6
I 2 952.5	60	2	3 048.5	50	5	3 143.7	20	80
I 2 954.5	100	20	I 3 048.8	70	12	3 144.2	60	8
2 955.4	50	1	3 049.2	2	70	I 3 147.2	50	3
I 2 958.0	60	5	I 3 055.0	70	12	3 147.5	6	80
2 961.5	5	50	3 056.9	12	150	3 150.7	60	60
2 961.7	60	3	3 059.2	50	....	3 153.8	60	12
2 963.4	60	150	3 060.2	20	50	I 3 156.8	50	....
I 2 963.7	60	5	3 060.5	8	50	I 3 158.9	60	12
I 2 965.2	80	20	3 064.8	70	60	I 3 159.9	70	25

For explanation of control and interfering line symbols see page 445

TABLE VI (*Continued*)

Principal Lines by Elements

RUTHENIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 163.2	12	100	I 3 316.4	80	....	3 429.5	60	25
3 164.9	3	70	3 316.9	5	50	I 3 430.8	70	45
3 167.5	5	100	I 3 317.9	50	12	I 3 432.2	50	12
3 168.5	100	25R	3 318.8	50	8	3 432.7	70	40
3 174.1	50	3	I 3 325.0	60	12	I 3 433.3	60	25
3 175.1	20	100	3 327.7	50	6	I 3 435.2	60	20
3 176.3	50	3	3 332.1	60	10	I 3 436.7pC	300R	150
3 177.0	60	200	3 332.6	60	5	I 3 438.4	70	35
3 179.3	50	50R	I 3 335.7	70	12	I 3 440.2	100	30
I 3 186.0	80	25	3 336.6	50	4	3 436.1	50	6
I 3 188.3	60	50	I 3 337.8	60	8	3 436.5	50	....
I 3 190.0	50	50	3 339.6	100	60	3 449.0	70	20
3 195.2	....	100	3 339.8	10	70	I 3 452.9	60	6
3 196.6	50	2	3 341.1	50	5	I 3 456.6	60	8
3 201.3	2	100	3 341.7	70	50	I 3 463.1	60	4
I 3 223.3	60	35	I 3 344.5	60	6	3 467.0	50	3
I 3 226.4	50	12	3 345.3	60	5	3 472.2	60	9
I 3 228.5	50	150	I 3 347.6	60	6	I 3 473.7	70	35
I 3 232.8	50	4	3 348.0	50	3	I 3 481.3	70	35
3 238.5	100	45	I 3 348.7	50	2	3 483.2	50	8
I 3 238.8	50	1	I 3 351.9	50	4	I 3 483.3	60	10
I 3 239.6	50	5	3 353.6	50	4	I 3 494.3	50	8
I 3 241.2	60	12	I 3 359.1	70	20	3 496.0	60	10
3 242.2	80	....	I 3 362.0	68	8	I 3 498.9P*C	500R	200
3 243.5	70	12	3 362.3	50	5	3 509.2	10	100
I 3 254.5	50	9	I 3 368.5	100	60	I 3 509.7	50	2
3 254.7	50	9	3 369.3	12	60	I 3 514.5	70	40
3 256.3	50	3	I 3 371.9	70	18	3 519.6	70	30
I 3 258.0	50	8	I 3 374.0	60	4	3 520.1	60	40
3 259.0	10	60	I 3 374.6	80	18	I 3 528.7	60	12
I 3 259.7	60	9	3 378.0	60	12	3 531.4	60	9
I 3 260.4	100	50	I 3 379.6	60	18	3 532.8	60	12
I 3 266.4	50	9	I 3 380.2	60	15	3 535.8	60	12
I 3 268.2	60	12	3 385.1	60	35	3 536.6	50	....
3 268.8	4	60	I 3 385.7	50	4	I 3 538.0	70	25
I 3 273.1	60	20	I 3 388.7	80	20	I 3 539.4	60	15
I 3 274.7	60	25	I 3 389.5	60	18	3 541.6	60	10
I 3 294.1	60	200	3 391.9	50	6	3 570.6	12	60
I 3 296.1	50	10	3 392.5	100	40	3 587.2	5	70
I 3 296.6	50	5	3 399.4	60	3	I 3 589.2	60	100
3 297.3	50	4	I 3 401.7	100	50	I 3 593.0	60	150
I 3 298.0	50	6	3 405.9	50	2	I 3 596.2p	30	100
I 3 298.4	50	25R	3 406.6	50	3	3 599.8	12	100
I 3 299.3	50	4	3 409.3	100	40	3 634.9C	50	100
I 3 301.6	70	40	3 411.6	80	20	3 657.6	....	50
3 304.0	60	8	I 3 412.8	50	5	I 3 661.4C	60	100
I 3 304.8	50	3	I 3 414.6	50	5	3 663.4	5	60
I 3 306.2	60	12	3 416.2	50	4	3 669.5	50	70
I 3 308.0	50	....	I 3 417.4	1	70	3 690.0	5	100
I 3 315.0	50	12	3 420.1	60	8	I 3 696.6	50	15
I 3 315.2	60	25	3 428.3	100	100	3 701.0	50	20

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

RUTHENIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 726.1	12	60	I 4 085.4	40	50	I 4 709.5	150	80
I 3 726.9 F†C	100	150	I 4 097.8	25	125	I 4 731.3	60	....
3 728.0	100	150	I 4 112.7	125	200	I 4 757.8	125	....
I 3 730.4	12	70	I 4 144.2	150	200	I 4 869.2	125	....
I 3 742.3	70	100	I 4 145.7	125	150	I 4 903.1	60	....
3 742.8	50	50	I 4 146.8	100	70	I 4 938.4	60	....
3 753.5	30	60	I 4 148.4	60	15	I 4 980.4	60	....
I 3 755.9	30	60	I 4 161.7	25	50	5 057.3	60	....
I 3 760.0	20	50	I 4 167.5	100	150	I 5 057.3	100	....
3 767.4	50	50	4 196.9	60	50	5 093.8	60	....
I 3 777.6	60	50	I 4 197.6	100	100	I 5 136.6	125	....
3 781.2	50	40	I 4 198.9	60	100	I 5 147.2	60	....
I 3 786.1	70	100	I 4 199.9	150	300	I 5 155.1	125	....
I 3 790.5	70	150	I 4 206.0	100	40	I 5 171.0	150	....
I 3 798.9 ‡	70	100	I 4 212.1	125	80	I 5 195.0	100	....
I 3 799.3	70R	100	4 214.4	100	40	I 5 284.1	100	....
3 808.7	50	30	I 4 217.3	100	20	5 304.9	60	....
3 817.3	50	60	I 4 220.7	60	....	I 5 309.3	125	....
I 3 819.0	50	30	I 4 230.3	60	....	5 334.7	60	....
3 822.1	50	25	I 4 241.1	100	20	5 335.9	100	....
3 831.8	60	50	I 4 243.1	100	40	5 361.8	100	....
3 835.0	50	6	I 4 297.7	60	50	5 401.0	125	....
3 839.7	50	30	I 4 307.6	20	50	5 427.6	25	....
I 3 850.4	50	10	I 4 342.1	60	40	5 454.8	100	....
3 856.5	50	8	4 361.2	40	60	I 5 484.3	60	....
3 857.6	50	25	I 4 372.2	125	100	5 510.7	100	....
3 862.6	2	60	I 4 385.4	125	40	I 5 559.7	60	....
I 3 867.8	60	35	I 4 385.6	125	50	I 5 636.2	100	....
I 3 892.2	50	40	I 4 390.4	150R	80	I 5 699.0	125	....
I 3 901.2	50	12	I 4 397.8	150	....	I 5 815.0	25	....
3 909.1	30	50	I 4 410.0	150	80	5 921.4	25	....
3 923.5	60	100	I 4 421.5	60	....	6 444.8	25	....
I 3 925.9	60	100	I 4 428.5	125	....	6 663.1	100	....
3 931.8	50	70	I 4 439.8	125	50	6 690.0	300	....
3 933.7	5	200	I 4 460.0	150	80	6 824.1	200	....
3 945.6	50	100	I 4 473.9	100	....	6 911.5	100	....
3 964.9	50	40	4 488.4	60	....	6 923.2	300	....
3 968.5	12	200	I 4 498.1	135	40	6 982.0	200	....
I 3 978.4	60	70	I 4 516.9	100	....	I 7 028.0	250	....
I 3 979.4	60	60	I 4 517.8	60	....	7 238.9	200	....
I 3 984.9	60	70	I 4 530.9	60	....	7 393.9	150	....
3 987.8	3	50	I 4 554.5	1000R	200	7 468.9	150	....
I 4 022.2	40	100	I 4 584.4	150R	80	7 475.4	50	....
I 4 023.8	25	60	I 4 591.1	60	....	7 485.8	150	....
4 039.2	25	50	I 4 592.5	100	....	7 499.8	200	....
I 4 051.4	125	200	I 4 599.1	100	....	I 7 559.6	100	....
I 4 052.2	25	50	I 4 635.7	125	....	7 771.9	100	....
I 4 054.1	40	100	4 645.1	100	30	7 774.1	100	....
I 4 064.5	20	60	4 647.6	125	....	7 775.4	60	....
4 068.4	40	60	I 4 654.3	125	....	I 7 791.9	100	....
I 4 076.7	60	25	I 4 681.8	100	....	I 7 847.8	100	....
4 080.6	125	300	I 4 684.0	100	....	7 881.5	100	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

RUTHENIUM (*Continued*)

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Ba 4166.0	*Cd Cu Fe Mo Rh	Ti 3752.9	
Co 3405.1		V 3715.5	
Fe 3558.5		‡Fe 3795.0	‡Cu Fe Hg Mg Mn Rh Sn V W
Rh 3528.0		Fe 3709.3	
Rh 3478.9		Rh 3700.9	
†Fe 3767.2	†Cd Fe Mn Mn Mo	V 3813.5	

RUBIDIUM

Rb

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 561.9	....	10	II 4 193.1	.....	40	II 5 699.2	....	100
2 631.8	....	40	I 4 201.9p*FC	2000R	500	I 5 724.5	600	....
2 807.6	....	70	I 4 215.6p†C	1000R	300	I 5 724.9	50	....
2 956.1	....	70	II 4 244.4	....	25	I 6 070.8	600	50
3 023.7	....	20	II 4 273.2	....	25	I 6 159.6	400	....
3 086.9	....	20	II 4 294.0	....	40	II 6 199.1	....	100
3 111.4	....	30	4 348.3	....	80	I 6 206.3	800	100
3 198.8	....	60	4 380.7	....	20	I 6 298.3	1000	150
II 3 271.0	....	40	4 401.4	....	30	I 6 299.2	300	50
II 3 321.5	....	60	4 426.1	....	30	6 310.0	....	50
II 3 340.6	....	60	4 430.7	....	20	II 6 458.3	....	400
I 3 348.7	100	....	II 4 571.8	....	30	II 6 555.6	....	100
I 3 350.9	150	....	II 4 622.4	....	50	II 6 775.1	....	200
II 3 393.1	....	40	II 4 648.6	....	20	II 6 805.6	....	50
II 3 434.3	....	60	II 4 776.0	....	25	II 7 042.5	....	150
3 434.7	....	40	II 4 776.4	....	100	I 7 280.0	400	50
II 3 461.6	....	200	II 4 782.9	....	25	I 7 408.2	500	....
3 492.8	....	300	II 5 152.1	....	100	I 7 618.9	1000	....
II 3 531.6	....	100	I 5 362.6	50	....	I 7 757.7	1000	....
I 3 587.1	200	40	I 5 431.5	100	....	I 7 759.4	400	....
I 3 591.6	80	20	II 5 522.8	....	100	I 7 800.2C	9000R	....
3 600.7	....	20	I 5 578.9	150	....	I 7 925.3	100	....
II 3 801.9	....	20	II 5 636.0	....	100	I 7 925.5	70	....
II 3 940.6	....	200	I 5 648.1	400	....	I 7 947.6	5000R	....
II 3 978.2	....	40	I 5 653.7	200	....			

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Fe 4143 9	*Co Cr Fe Mn Mo Ni Pt Rh Ru Ti V Sr Ca Cb Zr	†Sr 4077.7	†Ag Co Cr Cu Fe Hg Mn Mo Pd Rh Ru Sc Sr Ti V W
Ru 4297.7			‡Sc Si Zn Ba Ni
A Ba 7905.8			

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

SAMARIUM

Sm

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 183.9	60	40	3 745.5	40	10	II 4 285.5	200	200
II 3 207.2	50	9	II 3 770.7	25	50	II 4 286.6	100	60
3 211.8	100	15	3 771.4	50	2	II 4 292.2	100	60
II 3 215.2	50	15	3 778.1	40	100	4 296.8	100	50
3 218.6	100	25	3 783.8	50	10	II 4 304.9	100	100
II 3 230.5	100	30	II 3 787.2	100	35	II 4 309.0	200	150
3 236.6	100	40	II 3 830.3	50	10	II 4 318.9	300	300
II 3 239.6	100	25	3 836.5	50	25	4 319.5	50	15
II 3 241.1	50	10	3 848.8	150	10	II 4 323.3	125	100
II 3 250.4	50	10	3 854.2	200	25	II 4 329.0	300	300
II 3 253.9	50	8	3 875.2	50	10	4 330.0	80	15
II 3 254.4	100	15	3 877.5	50	8	II 4 334.1	200	200
II 3 276.7	50	10	II 3 891.2	50	8	4 336.1	100	30
3 298.1	60	60	II 3 897.0	50	50	II 4 345.9	100	100
II 3 306.4	100	40	3 903.4	60	60	II 4 347.8	150	60
II 3 321.2	50	15	II 3 922.4	60	60	II 4 350.5	150	150
3 327.9	50	20	II 3 928.3	60	60	4 352.1	125	100
II 3 382.4	100	40	II 3 933.6	200	200	II 4 360.7	100	60
II 3 402.5	50	10	II 3 941.9	50	40	II 4 362.0	150	150
II 3 418.5	50	10	II 3 948.1	50	50	4 362.9	60	25
3 445.6	150R	10R	3 959.5	50	40	II 4 363.4	60	50
II 3 568.3	40	50	3 963.0	50	40	II 4 368.0	60	60
II 3 592.6	40	50	II 3 966.1	60	50	II 4 373.5	50	50
II 3 609.5	60	100	II 3 971.4	50	30	II 4 375.0	200	200
II 3 621.2	60	10	II 3 979.2	50	50	II 4 378.2	100	100
II 3 627.0	50	40	II 3 983.1	100	60	II 4 384.3	50	50
II 3 634.3	100	25	II 4 007.5	50	25	II 4 390.9p	150	150
II 3 649.5	100	30	II 4 035.1	50	3	4 401.2	50	30
II 3 661.4	100	50	II 4 084.4	80	....	II 4 403.4	50	50
II 3 662.3	50	50	II 4 106.6	100	5	II 4 409.3	100	100
II 3 670.8	100	50	II 4 118.5	50	60	II 4 417.6	80	80
II 3 674.1	50	10	II 4 210.3	50	20	II 4 420.5	200	200
3 687.9	50	....	II 4 220.7	100	100	II 4 421.1	150	150
II 3 692.2	90	50	II 4 223.7	50	20	II 4 424.3p	300	300
II 3 694.0	100	150	II 4 229.7	40	30	II 4 433.9	200	200
II 3 700.6	50	30	II 4 234.6	60	40	II 4 434.3pL	200	200
3 700.9	50	4	II 4 236.7	60	50	4 444.3	100	100
3 708.7	50	25	II 4 237.7	60	50	II 4 452.7	200	200
II 3 710.9	100R	7	II 4 244.7	100	80	II 4 454.6	100	100
II 3 712.8	100	100	II 4 249.5	50	40	II 4 458.5	150	200
II 3 718.9	100	5	II 4 251.8	200	200	II 4 467.3	200	200
3 719.5	50	10	II 4 256.4	150	150	4 470.9	60	60
3 721.8	100	50	II 4 258.6	50	40	II 4 472.4	100	100
II 3 724.9	40	15	II 4 262.7	200	150	II 4 473.0	150	150
II 3 726.8	100R	3	II 4 265.1	60	25	4 478.7	100	100
II 3 728.5	100	100	II 4 279.7	100	100	II 4 499.5	100	100
II 3 731.3	50	10	II 4 279.9	50	40	II 4 511.8	100	100
II 3 736.0	50	8	II 4 280.8L	200	200	4 515.1	100	....
II 3 743.9	50	25	4 281.0L	50	30	II 4 519.6	150	80

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

SAMARIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
4 522.5	60	....	II 4 791.6	150	....	II 5 116.7	100	1
II 4 523.9	100	50	II 4 798.9	50R	....	5 117.2	80	1
4 532.4	60	....	II 4 815.8	125	80	5 122.1	80	....
II 4 538.0	50	25	II 4 829.6	200	....	5 124.8	50	....
4 542.0	50	....	II 4 833.3	80	....	5 154.3	125	1
II 4 543.9	100	50	II 4 834.6	100	....	II 5 155.0	125	1
4 552.7	80	40	II 4 836.7	50	....	II 5 166.0	125	....
II 4 554.4	60	....	II 4 837.6	100	....	5 169.6	50	....
II 4 560.4	50	....	4 841.7	100	....	5 172.7	80	1
II 4 566.2	100	50	II 4 844.2	150	....	5 175.4	60	1
II 4 577.7	100	50	II 4 847.8	150	....	5 178.1	100	....
II 4 584.8	60	50	4 848.3	100	....	5 200.6	200	1
II 4 591.8	100	....	II 4 854.4	125	....	II 5 202.7	50	....
II 4 593.5	50	50	II 4 859.6	80	....	5 228.8	60	....
II 4 595.3	100	60	II 4 870.0	125	....	5 234.2	50	....
II 4 604.2	60	....	4 883.8	60	....	5 251.9	150	....
4 611.3	50	....	4 884.0	80	....	5 271.4	150	....
II 4 615.7	50	40	II 4 893.3	150	....	II 5 272.8	50	....
II 4 642.2	100	40	II 4 894.3	60	....	5 282.9	100	....
II 4 646.7	50	....	II 4 900.7	100	....	5 302.9	50	....
4 663.5	60	....	4 905.0	60	....	II 5 312.2	100	....
II 4 669.6	50	40	4 910.4	150	....	5 320.6	100	....
II 4 674.6	80	40	II 4 913.3	150	....	5 321.9	50	4
II 4 676.9	100	50	4 919.0	125	....	5 341.3	80	....
4 681.6	50	....	II 4 920.4	125	....	5 364.4	50	....
II 4 687.2	100	....	II 4 936.0	80	....	5 368.4	80	....
4 688.7	50	....	II 4 939.1	125	....	5 388.0	50	3
II 4 693.6	50	....	4 946.3	60	....	5 405.2	80	....
II 4 699.3	50	....	II 4 948.6	125	....	5 416.1	100	....
II 4 704.4	200	....	II 4 952.4	125	....	5 453.0	100	....
II 4 710.7	50	....	II 4 953.0	50	....	5 466.7	80	....
II 4 713.1	100	....	II 4 961.9	100	....	5 493.7	80	....
II 4 714.6	50	....	4 964.6	80	....	5 498.2	80	....
II 4 715.3	100	....	II 4 972.2	80	....	5 512.1	80	....
4 716.1	150	....	4 976.0	80	....	5 516.1	200	....
4 717.1	80	....	II 4 981.7	50	....	II 5 537.1	50	....
II 4 717.7	100	....	II 4 989.4	60	....	5 549.0	80	....
II 4 718.3	100	....	II 4 992.0	80	....	5 550.4	125	....
II 4 719.8	125	....	II 5 016.6	80	....	5 573.4	80	....
II 4 726.0	100	....	II 5 023.5	60	....	5 574.9	50	....
4 728.4	150	....	II 5 028.4	200	....	II 5 600 9	200	....
II 4 745.7	250	....	5 036.2	50	....	II 5 603.2	100	....
4 750.7	60	....	5 044.3	150	....	5 621.8	60	....
II 4 755.4	100	....	II 5 052.8	150	2	5 626.0	60	....
4 760.3	150	....	II 5 057.7	100	1	5 637.3	80	....
II 4 774.1	100	....	II 5 069.4	150	1	5 644.1	40	....
II 4 777.8	100	....	5 071.2	100	....	5 659.9	60	....
II 4 781.8	60	....	II 5 100.2	50	....	5 686.7	50	20
4 783.1	150	....	II 5 113.1	150	....	5 696.7	40	....
4 785.9	100	....	II 5 104.5	125	1	5 719.1	60	20
4 790.0	50	....	II 5 112.3	125	1	5 732.9	100	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

SAMARIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
5 740.9	80	....	II 6 426.6	100	....	II 6 794.2	200	....
5 741.2	60	....	6 428.3	50	....	II 6 829.8	100	....
II 5 759.5	60	....	II 6 431.0	50	....	II 6 844.7	150	....
5 773.8	100	....	II 6 432.0	50	....	II 6 846.5	100	....
5 778.3	50	....	II 6 470.5	60	....	II 6 854.5	60	....
5 779.2	50	....	II 6 472.3	150	....	II 6 856.0	300	....
5 781.9	100	....	II 6 484.5	100	....	I 6 860.9	800	....
II 5 787.0	200	....	II 6 487.6	60	....	II 6 861.1	500	....
5 800.5	80	....	II 6 490.7	60	....	II 6 862.8	100	....
5 802.8	80	....	II 6 498.7	100	....	II 6 872.4	100	....
5 814.9	60	....	6 526.6	50	....	II 6 909.8	50	....
II 5 831.0	80	....	6 529.7	50	....	II 6 930.4	50	....
II 5 836.4	100	....	II 6 542.8	200	....	II 6 941.6	50	....
5 867.8	50	....	II 6 549.8	100	....	II 6 950.5	100	....
5 874.2	40	....	6 562.9	50	....	II 6 955.3	400	....
5 897.4	100	....	II 6 569.3	500	....	II 7 020.4	500	....
5 919.3	60	....	II 6 570.7	200	....	I 7 026.6	100	....
II 5 932.9	50	....	II 6 574.4	100	....	II 7 039.2	500	....
II 5 938.8	50	....	II 6 585.2	150	....	II 7 042.2	400	....
II 5 965.7	125	....	6 588.9	100	....	II 7 051.5	400	....
II 5 994.7	60	....	II 6 589.7	400	....	7 074.7	50	....
II 5 997.3	50	....	II 6 601.8	150	....	II 7 082.4	400	....
6 001.7	50	....	II 6 604.6	200	....	I 7 088.3	60	....
II 6 011.2	60	20	II 6 614.8	50	....	I 7 091.2	60	....
II 6 017.4	50	....	II 6 617.6	50	....	I 7 095.5	100	....
6 045.0	60	....	II 6 628.9	50	....	I 7 096.4	60	....
6 084.1	50	....	II 6 630.6	50	....	I 7 104.6	150	....
II 6 123.6	50	....	II 6 632.3	100	....	I 7 106.2	80	....
II 6 149.1	60	....	II 6 637.2	60	....	7 116.0	50	....
6 159.6	40	30	II 6 649.0	50	....	7 119.8	60	....
II 6 181.1	50	....	II 6 651.6	80	....	I 7 131.8	80	....
II 6 182.9	60	....	II 6 656.2	100	....	7 136.0	50	....
6 192.6	50	....	II 6 667.2	50	....	II 7 149.6	150	....
II 6 237.7	50	....	I 6 671.5	50	....	I 7 213.8	60	....
II 6 246.8	80	....	6 679.1	80	....	II 7 218.1	50	....
II 6 256.7	80	....	II 6 679.2	80	....	II 7 240.9	200	....
II 6 267.3	150	....	II 6 681.5	60	....	I 7 279.3	100	....
II 6 289.9	60	....	II 6 687.8	80	....	7 290.2	80	....
II 6 291.8	100	....	II 6 693.6	100	....	I 7 332.7	100	....
II 6 300.2	50	....	II 6 707.5	50	....	7 338.0	50	....
II 6 301.1	50	....	II 6 712.6	50	....	I 7 347.3	100	....
II 6 307.1	60	....	II 6 731.8	500	....	7 364.1	50	....
6 312.7	60	....	II 6 734.1	400	....	I 7 371.5	50	....
6 325.6	50	....	II 6 734.8	400	....	II 7 376.7	60	....
II 6 327.5	100	....	6 735.3	100	....	7 405.0	50	....
6 353.5	50	5	II 6 754.7	50	....	7 444.6	150	....
6 357.2	50	1	II 6 756.9	50	....	I 7 445.4	100	....
II 6 368.3	50	....	II 6 766.5	50	....	7 470.8	100	....
II 6 389.9	100	....	II 6 778.6	200	....	II 7 502.4	50	....
II 6 390.8	100	....	II 6 781.2	50	....	II 7 541.4	100	....
II 6 417.5	100	....	II 6 790.0	300	....	7 544.7	50	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

SAMARIUM (*Continued*)

Wavelength	Arc	Spark
7 562.9	50	....
II 7 571.0	150	....
7 572.3	80	....
II 7 578.1	60	....
II 7 585.8	60	....
I 7 607.7	80	....
II 7 637.9	60	....
II 7 645.1	200	....
7 645.8	80	....
II 7 648.0	100	....
II 7 655.8	50	....
II 7 667.2	50	....
7 672.5	50	....
II 7 678.8	60	....
7 695.8	100	....
II 7 712.0	60	....
II 7 728.6	200	....
7 736.3	150	....
II 7 749.3	200	....
II 7 755.2	125	....
I 7 755.3	80	....
I 7 794.5	100	....
I 7 801.5	150	....
7 812.8	60	....
II 7 820.2	150	....
7 831.4	60	....
II 7 835.1	400	....
II 7 837.3	400	....
II 7 844.8	60	....
I 7 859.5	100	....
II 7 863.7	100	....
II 7 880.1	100	....
I 7 896.0	200	....
7 913.5	60	....
II 7 915.0	200	....
I 7 919.4	80	....
II 7 928.1	800	....
7 931.2	50	....
I 7 931.9	200	....
II 7 937.1	100	....
7 940.3	150	....
II 7 948.1	100	....
7 968.3	50	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

SCANDIUM

Sc

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 552.4	25	40	I 3 907.5p	125	25	I 5 083.7	100	80
II 2 560.2	10	30	I 3 911.8p	150	30	I 5 085.5	80	70
2 699.1	3	25	I 3 933.4	60	60	I 5 087.0	60	25
II 2 822.1	50	20	I 3 996.6	40	10	I 5 099.2	100R	80
I 2 989.0	20	2	I 4 020.4	50	20	II 5 239.8	30	125
I 3 019.3	20	10	I 4 023.2	60	....	5 349.3	30	....
II 3 039.9	4	20	I 4 023.7§C	100	25	I 5 482.0	60	....
II 3 045.7	15	25	I 4 047.8	25	10	I 5 484.6	60	....
II 3 052.9	10	15	I 4 082.4	25	10	I 5 514.2	60	....
II 3 065.1	12	25	II 4 246.8A_1‖	80	500	I 5 520.5	80	....
I 3 269.9	30	12	II 4 314.1A_2¶	50	150	II 5 526.8	100	300
I 3 273.6	35	12	II 4 320.7A_3	50	40	II 5 657.9	30	....
II 3 353.7	50	60	II 4 325.0	50	40	I 5 671.8	300	....
II 3 359.7	50	25	II 4 354.6	60	10	I 5 686.8	200	....
II 3 361.3	25	9	II 4 374.5	100	25	I 5 700.2	400R	....
II 3 361.9	25	9	II 4 400.4	150	30	I 5 711.8	100	....
II 3 568.9	50	20	II 4 415.6	100	25	I 6 210.7	20	25
II 3 572.2	7	150	II 4 431.4	50	3	I 6 259.0	20	20
II 3 535.7	15	30	II 4 670.4	100	300	I 6 305.7	80	60
II 3 558.5	15	40	I 4 728.8	50	25	I 6 413.4	10	25
II 3 567.7	15	40	I 4 729.2	100	50	II 6 604.6	12	....
II 3 572.5*	30	50	I 4 734.1	100	60	6 737.9	5	....
II 3 576.3	18	45	I 4 737.6	100	60	6 817.1	10	....
II 3 580.9	12	40	I 4 741.0	100	60	I 6 819.5	20	....
II 3 613.8P†	40	70	I 4 743.8	100	60	I 6 829.5	15	....
II 3 630.1p‡C	50	70	I 4 753.2	80	40	6 835.0	25	....
II 3 642.8p	60	50	I 4 779.3	80	40	I 7 697.7	20	....
II 3 645.3	50	50	II 5 031.0	50	200	I 7 741.2	50	....
II 3 651.8	50	45	I 5 081.6	100	100	I 7 800.4	40	....

Control lines:	Interfering lines:
*Co 3569.4	*Bi Cr Fe Mn Ni Pb
Co 3412.3	
Fe 3749.5	
Mn 2949.2	
Ni 3610.5	
†Cd 2288.0	†Al Au Bi Cd Cr Cs Hg Mg Mo Ni Rh
Mo 3447.1	
Ni 3510.3	
‡Fe 3570.1	‡Ba Bi Ca Co Fe Mn Sb Sr W Ce Zr
A_1La 4263	
A_2La 4322	
A_3La 4322	

Control lines:	Interfering lines:
Mo 3614.3	
Mo 3158.2	
§Co 4086.3	§Co Cr Cu Fe Hg Mn Pt Rh Ru Ti V Zr Mo Ce Sc
Cu 4062.8	
Ti 4078.5	
‖Pb 4168.0	‖Co Cr Cu Fe Mn Mo Pt Rh Ru Ti V
Pb 4057.8	
¶Fe 4282.4	¶A As Au Co Cr Fe Mo Ni Pd Rh Ru
Ti 4305.9	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

SELENIUM (see page 607)

Se

SILICON

Si

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 058.1	15	....	I 2 568.6	15	10	I 6 155.2	20	....
I 2 082.0	15	....	I 2 577.1	10	....	I 6 155.3	50	....
I 2 084.5	20	....	I 2 631.3	60	50	I 6 244.5	10	....
I 2 123.0	10	....	I 2 881.6P¶	500	400	I 6 244.7	12	....
I 2 124.2	200R	50	LS_3G_3CN_3			I 6 254.6	15	....
I 2 163.8	10	....	$A_1X_1X_2$			6 976.5	25	....
I 2 208.0	18	15	I 2 970.3	20	20	I 7 003.6	50	....
I 2 211.8	12	12	I 2 987.6X_1	100	100	I 7 005.8	50	....
I 2 216.7	40	40	3 590.8	....	5	I 7 017.7	10	....
I 2 218.1	10	15	3 791.1	....	5	I 7 035.0	50	....
2 287.1	....	10	3 796.2	....	7	I 7 165.6	100	....
I 2 289.6	10	....	3 806.6	....	7	I 7 250.7	40	....
I 2 303.0	10	6	3 856.1	....	8	I 7 275.3	50	....
+2 435.2	150	80	3 862.5	....	7	I 7 289.3	200	....
I 2 438.8	30	20	I 3 905.5p	20	15	I 7 373.0	10	....
I 2 443.4	15	15	4 128.1	....	20	I 7 405.9	300	....
I 2 452.1	20	20	4 131.0	....	25	I 7 409.1	100	....
I+2 506.9p*S_1	300	200	4 552.5	....	40	I 7 415.4	15	....
N_1C			4 567.7	....	30	I 7 416.0	200	....
I 2 514.3†N_2C	300	200	4 574.7	....	20	I 7 423.5	500	....
I 2 516.1pA_2‡	500	500	5 056.1	....	8	I 7 424.6	20	....
LS_2C			I 5 690.5	25	....	I 7 680.4	100	....
I 2 519.2C	300	300	I 5 754.3	40	....	7 918.4	200	....
I 2 524.1§G_1C	400	400	I 5 780.5	15	....	I 7 932.2	300	....
I 2 528.5p‖G_2C	400	500	I 5 797.9	25	....	7 943.9	500	....
I 2 532.4	30	40	I 5 948.6	50	5	7 970.3	10	....

Control lines:	Interfering lines:
*Co 2587.2	*Ag Co Cu Cr Fe V Ta Ir
†Os 2498.4	†Fe Mn Mo Pt Sb V
‡Pt 2498.5	‡Bi Fe Mo Ti V W Zn Rh
§Co 2519.8	§Bi Fe Mo Ni Pb Pt
Fe 2541.0	
Fe 2488.2	
‖Co 2521.4	‖Au Ba Co Mo Pb Sb Mn V Ce Cr U
Co 2564.4	

Control lines:	Interfering lines:
Fe 2510.8	
Fe 2522.9	
V 2527.9	
¶Sb 2598.1	¶Cd Mg Mo Th Rh Ce Ta
Ti 2877.4	
Ti 2884.1	
V 2884.8	

Control lines:
S_1Cu 2529.4
S_2Cu 2492.2
2406.7
S_3Cu 2713.6
2703.3
2882.9
A_1Al 3050
A_2Al 2669
X_1Mo 3158
X_2Mo 3208

Control lines:
2997.4
G_1Fe 2523.6
G_2Fe 2521.7
G_3Fe 2880.7
2926.6

Control lines:
N_1Sn 2495.7
N_2Sn 2495.7
N_3Sn 2913.5
2813.6
Cu 2882.9

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

SILVER

Ag

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 000.7	....	30	II 2 460.3	....	80	3 170.6	5	3
I 2 061.2	25	10	II 2 462.2	5	80	3 180.7	2	15
I 2 069.8	10	3	II 2 473.8	20	150	3 215.7	5	3
II 2 113.8	20	150	II 2 477.3	....	150	3 247.6	15	15
II 2 120.5	10	10	II 2 480.4	....	15	I 3 280.7p*F LS$_6$ CN$_3$B	2000R	1000R
II 2 145.6	8	150	II 2 504.1	....	50	3 382.9p†FL S$_7$N$_4$C	1000R	700R
2 161.9	....	15	II 2 506.6	15	50	3 469.2	10	8
II 2 166.5	5	100	II 2 535.3	10	25	I 3 508.1	10	1
II 2 186.8	10	100	II 2 564.4	....	15	3 538.3	10	2
II 2 202.1	....	50	2 575.7	10	3	3 542.6	30	5
II 2 229.5S$_1$	....	25	II 2 580.7	1	150	I 3 624.7	25	....
II 2 246.4p	25	300	II 2 595.6	....	40	I 3 682.5	50	4
II 2 248.7	15	150	II 2 599.7	10	10	I 3 709.2	10	3
II 2 253.5	....	50	II 2 606.2	10	200	I 3 810.9	100	10
II 2 280.0S$_2$	10	125	II 2 614.6	....	300	I 3 840.8	20	3
2 309.6	150	200	II 2 656.7	1	15	3 933.6	80	80
II 2 312.4	25	50	II 2 660.5	30	150	3 961.3	15	5
II 2 317.0	15	100	II 2 681.4	....	100	3 968.2	100	60
II.2 320.2	15	150	II 2 688.4	....	10	I 3 981.6	30	20
II 2 321.5	....	25	II 2 711.2	1	300	4 005.3	10	2
II 2 324.7	15	100	II 2 712.1	3	200	4 045.8	10	2
II 2 325.1	4	25	2 721.8	20	25	I 4 055.3	800R	500R
II 2 331.4	18	150	II 2 743.9	....	50	4 085.9	....	25
II 2 357.9	15	100	II 2 756.5	5	200	I 4 210.9	200	30
II 2 358.9	....	100	II 2 767.5	30	200	I 4 212.7	150	20
II 2 362.2	....	80	II 2 786.5	10	10	4 295.9	10	30
II 2 364.0	....	100	2 795.5	10	10	4 311.1	5	25
2 375.1	300	300	II 2 799.7	20	100	4 396.3	100	....
II 2 386.3	....	25	II 2 815.5	3	80	I 4 668.5	200	70
II 2 390.5	....	80	2 824.4	150	200	4 874.2	30	....
II 2 402.6	....	30	II 2 873.7	3	100	4 888.3	9	20
II 2 411.4	25	150	II 2 896.5	2	150	I 5 209.1	1500R	1000R
II 2 413.2S$_3$	50	300	II 2 902.1	5	200	I 5 465.5	1000R	500R
II 2 420.1	....	100	II 2 920.0	....	100	I 5 471.6	500	100
II 2 429.6	....	150	II 2 929.4	20	40	I 5 545.9	30	....
II 2 437.8PS$_4$N$_1$	60	500	II 2 934.2	10	200	I 7 687.8	20	....
II 2 444.2	....	80	I 2 938.6	200	200			
II 2 447.9S$_5$N$_2$	30	200	3 099.1	10	8			
II 2 453.3	....	125	3 130.0	25	15			

Control lines:
*V 3271.1
Zn 3302.6
†Mo 3447.1

Interfering lines:
*Cu Mn Zn Mo Ce Eu Rh Th
†Au Cr Sb Sr Ce Fe W Mo

Control lines:
Ni 3393.0
Sr 3464.5
Ti 3372.8

Control lines:
S$_1$Sn 2231.7
S$_2$Sn 2282.3
S$_3$Sn 2408.2
S$_4$Sn 2433.5

Control lines:
N$_1$Sn 2455.3
2433.5
N$_2$Sn 2433.5
N$_3$Sn 3223.6

Control lines:
3413.0
3352.3
3330.6
3223.6

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

SILVER (*Continued*)

Sn 2455.2
S_6Sn 2433.5
Sn 2455.2
S_6Sn 3262.3
S_7Sn 3218.7
3330.6
3650.0

3218.7
3141.8
Pb 3262.3
3240.2
3043.9
N_4Sn 3655.9

3218.7
3141.8
Pb 3240.2
3230.0
3220.5
BMg 2852.1

SODIUM

Na

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 490.7	3R	....	II 3 092.7	50	200	I 4 541.7	10	....
II 2 493.2	....	40	II 3 129.4	35	60	I 4 545.2	15	....
I 2 512.1	2R	....	II 3 135.5	12	40	I 4 664.9	80	....
I 2 512.2	4R	....	II 3 149.3	12	40	I 4 668.6	200	100
I 2 543.8	6R	....	II 3 163.7	35	60	I 4 748.0	15	....
II 2 543.9	12R	....	II 3 189.8	35	60	I 4 751.9	20	....
I 2 593.8	20R	....	II 3 212.2	35	60	I 4 978.6	15	10
I 2 593.9	15R	....	II 3 258.0	35	60	I 4 982.8	200	100
I 2 680.3	60R	10	II 3 274.2	15	40	I 5 149.1	400	....
I 2 680.4	40R	....	II 3 285.7	40	100	I 5 153.6	600	....
I 2 686.4	40R	....	I 3 302.3p*C	600R	300R	I 5 532.0	15	....
II 2 841.7	20	....	I 3 303.0pC	300R	150R	I 5 670.2	100	....
I 2 852.8	100R	20	II 3 533.0	50	200	I 5 675.7	150	....
I 2 853.0	80R	15	II 3 631.3	12	100	I 5 682.7	80	....
II 2 904.9	20	80	II 3 711.1	8	60	I 5 688.2	300	....
II 2 951.2	40	100	II 4 123.1	10	15	5 688.6	10	....
II 2 975.0	15	60	I 4 198.3	10	....	I 5 890.0PF†C	9000R	1000R
II 2 979.7	35	40	I 4 390.1	15	....	I 5 895.9pF‡C	5000R	500R
II 2 984.4	20	80	I 4 393.5	20	....	I 6 154.2	500	100
II 3 056.2	35	60	I 4 494.3	60	....	I 6 160.8	500	100
II 3 078.3	12	60	I 4 497.7	70	....			

Control lines:
*Fe 3407.5

Interfering lines:
*Cr Pt Sr Ti Zn Bi Zr Ta Pa Ce
†Mo Cr W Ti
‡Pb Zn Ir

Control lines:
Zn 3345.0

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

STRONTIUM

Sr

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 152.8	15	15	I 4 337.9	150	50	5 521.8	50	10
II 2 166.0	25R	15	I 4 361.7	20	....	5 534.8	20	15
I 2 428.1	10	....	4 406.9	50	....	5 540.1	20	30
I 2 569.5	25R	5	I 4 438.0	25	....	I 5 543.4	30	5
I 2 931.8	30	8	I 4 607.3P‡FC	1000R	50R	I 6 345.7	25	4
I 3 301.7	100	10	I 4 722.3	30	....	I 6 363.9	25	4
I 3 307.5	200	10	I 4 741.9	30	....	6 370.0	25	5
I 3 322.2	100	8	I 4 811.9	40	....	I 6 380.7	30	8
I 3 330.0	100	10	I 4 832.1	200	8	I 6 386.5	35	10
I 3 351.2	300	15	I 4 855.0	20	....	I 6 388.2	35	10
I 3 366.3	100	10	I 4 872.5	25	....	6 408.5	50	20
II 3 380.7	150	200	4 876.3	200	60	6 504.0	35	20
II 3 464.5	200	200	I 4 892.0	40	....	I 6 546.8	25	5
II 3 474.9	80	50	I 4 892.7	15	....	I 6 550.3	100	10
I 3 499.7	50	....	I 4 962.3P	40	....	I 6 617.3	150	....
I 3 548.1	50	....	I 4 967.9	20	....	6 643.5	100	....
I 3 807.4	50	....	I 5 156.1	80	18	I 6 791.1	200	....
I 3 865.5	50	....	5 222.2	70	8	I 6 878.4	500	....
I 3 940.8	20	....	5 225.1	70	8	I 6 892.6	100	....
I 4 030.4	40	....	5 229.3	70	8	I 7 070.1	1000	....
II 4 077.7p*XC	400R	500	5 238.6	90	15	I 7 167.2	100	....
I 4 161.8	30	....	5 256.9	90	25	I 7 232.3	50	....
II 4 215.5p†C	300R	400	5 480.8	100	30	I 7 309.4	200	....
I 4 305.4	40	....	5 486.1	40	8	I 7 621.5	100	....
I 4 319.1	50	20	5 504.2	60	25	I 7 673.1	200	....

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Mn 4055.6	*Au Bi Co Cr Fe Hg Mn Mo Sc Ti W Cu Sn U Ce	†Rb 4201.8	†Ag Co Cr Cu Fe Hg Mn
Cb 4059.0		‡Fe 4619.3	‡Al Au Be Co Cr Cs Fe Li Mn Mo Pt Sc Ti V W Rh Cb Ce Ni
Ti 4295.8		Mo 4626.5	
Mo 3903			

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

SULFUR

S

Wavelength	Arc	Spark (Discharge)	Wavelength	Arc	Spark (Discharge)	Wavelength	Arc	Spark (Discharge)
2 002.9	....	10	II 5 201.0	....	10	5 659.3	....	600
2 578.9	....	8	II 5 212.6	....	20	I 5 696.6	....	8
3 497.3	....	100	I 5 278.6	....	5	I 5 700.2	....	25
II 3 993.5	....	50	I 5 278.9	....	15	I 5 706.1	....	50
II 4 028.8	....	200	II 5 320.7	....	35	I 6 041.9	....	15
II 4 142.3	....	150	5 345.7	....	25	I 6 046.0	....	40
II 4 145.1	....	250	5 428.7	....	250	I 6 052.6	....	125
II 4 153.1	....	600	5 432.8	....	600	6 312.7	....	1000
II 4 162.7	....	600	5 453.8	....	750	6 455.4	....	70
4 174.3	....	150	5 473.6	....	750	6 538.6	....	60
II 4 189.7	....	250	I 5 507.0	....	25	I 6 743.6	....	50
II 4 294.4	....	80	II 5 509.7	....	25	I 6 748.8	....	80
II 4 524.9	....	150	5 564.9	....	150	I 6 757.1	....	150
I 4 694.1pC	....	500	5 578.9	....	70	I 7 244.8	....	80
I 4 695.5pC	....	30	5 606.1	....	700	I 7 679.6	....	70
I 4 696.3pC	....	15	5 640.0	....	500	I 7 686.1	....	150
II 4 925.3	....	100	II 5 647.0	....	30	I 7 696.7	....	200
5 032.4	....	8						

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Element

TANTALUM

Ta

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 330.8	....	60	2 573.8	100	1	2 668.6	1	100
2 387.1A_1	20	50	2 574.4	80	....	2 675.9§A_2	150	200
2 396.3	80	....	2 575.5	80	....	2 676.1	15	7
2 406.5	60	....	2 577.4	80	150	2 680.1	30	50
2 416.9	100	150	2 577.8	90	1	2 681.9	50	....
2 427.6	150	1	2 579.0	3	100	2 684.3	150	2
2 432.7	300R	400	2 579.6	80	....	2 685.1‖	15	25
2 443.9	60	....	2 580.2	150	....	2 691.3	150	....
2 444.7	50	200	2 584.0	80	200	2 692.4	100	1
2 454.2	50	....	2 593.1	150	1	2 694.8	50	....
2 454.5	60	....	2 593.7	80	100	2 696.8	125	1
2 460.6	50	....	2 595.3	50	2	2 698.3	150	3
2 465.3	60	....	2 595.6	40	50	2 703.1	60	....
2 470.9	60	40	2 596.5	80	150	2 704.3	50	....
2 472.1	80	....	2 599.4	100	30	2 706.7	50	1
2 474.6	150	1	2 600.1	80	....	2 709.3	40	150
2 478.2	60	....	2 601.1	50	5	2 710.1	200	3
2 482.6	50	50	2 603.6	5	300	2 714.7¶C	200	8
2 488.4	60	....	2 607.8	20	150	2 717.2	100	....
2 488.7	200	150	2 608.6	125	4	2 718.4	80	....
2 504.5	200	1	2 609.0	80	1	2 720.8	150	1
2 507.5	150	1	2 611.3	100	....	2 721.8	50	....
2 511.7	2	100	2 612.6	50	40	2 725.4	20	100
2 512.0	5	800	2 614.2	200	....	2 727.4	50	150
2 512.7	100	....	2 615.5	50	1	2 727.8	200	40
2 519.8	50	....	2 615.7	50	1	2 732.9	100	5
2 526.0	100	80	2 624.1	60	....	2 736.3	300	8
2 526.4	100	....	2 632.3	15	80	2 739.3	2	80
2 526.5	150	....	2 633.8	10	80	2 740.2	100	10
2 526.7	50	....	2 635.9*	50	....	2 746.7	100	5
2 532.1	80	100	2 636.7	70	1	2 747.3	50	5
2 535.6	50	....	2 636.9	100	3	2 748.8	400	50
2 536.2	100	....	2 643.9	50	....	2 749.8	200	50
2 536.8	80	....	2 644.6	20	50	2 752.3	150	8
2 549.4	100	....	2 645.1	80	30	2 752.5	300	300
2 551.1	150	....	2 646.2	50	2	2 758.3	200	40
2 551.2	150	....	2 646.4	125	2	2 761.5	80	....
2 551.7	100	4	2 646.8	50	50	2 761.7	200	150
2 554.6	50	100	2 647.5†C	200	10	2 763.4	25	60
2 554.9	50	50	2 651.2	....	80	2 770.8	50	1
2 555.1	50	....	2 651.5	50	....	2 771.8	3	100
2 557.7	50	100	2 653.3‡C	200	15	2 774.9	100	3
2 559.4	100	2	2 656.6	200R	2	2 775.1	100	80
2 560.7	70	....	2 658.9	25	50	2 775.3	80	15
2 562.1	100	....	2 661.3	200	10	2 775.9	200	30
2 563.3	50	....	2 661.9	60	....	2 779.1	150	5
2 563.7	80	....	2 664.2	10	100	2 781.4	50	4
2 569.1	40	40	2 665.6	80	40	2 785.0	50	100
2 573.5	125	1	2 668.1	80	....	2 787.7	400R	40

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

TANTALUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 788.3	150	3	2 874.2	150	15	2 989.5	200	15
2 790.7	150	10	2 876.1	50R	5	2 991.2	50	10
2 791.4	25	150	2 877.7	15	80	3 010.8	5	70
2 791.7	100	10	2 879.5	50	10	3 011.1	100	25
2 796.3	400	80	2 879.7	150	10	3 011.9	100	15
2 796.6	150	....	2 880.0	150	50	3 012.5	125	100
2 797.8	100	100	2 882.3	3	80	3 025.2	70	15
2 798.4	150	....	2 891.0	150	30	3 027.5	125	35
2 800.6	150	40	2 891.8	500	100	3 028.8	50	7
2 802.1	300	80	2 892.0	80	10	3 037.5	8	100
2 806.3	300	50	2 895.1	125	15	3 041.0	50	7
2 806.6	200	50	2 896.4	2	50	3 042.1	5	100
2 810.9	200	40	2 899.0	200	15	3 046.0	150	50
2 811.7	1	150	2 900.3	50	150	3 048.9	100	15
2 814.3	50R	50	2 900.8	3	100	3 049.6	150	30
2 814.8	125	5	2 901.1	100	3	3 052.5	....	70
2 815.0	150	15	2 902.0	1000	200	3 056.6	1	70
2 815.1	100	4	2 904.1	300	40	3 057.1	25	25
2 817.1	80	100	2 905.2	80	100	3 058.6	50	3
2 817.5	80	10	2 908.9	150	10	3 060.3	125	35
2 817.6	3	100	2 914.1	200	30	3 063.6	70	15
2 819.4	100	5	2 915.3	150	50	3 069.2	150	70
2 824.8	60	5	2 915.5	150	40	3 077.2	150	50
2 826.2	60	5	2 919.0	2	50	3 078.2	50	5
2 827.2	200	10	2 925.3	100	40	3 080.0	50	5
2 828.6	75	100	2 925.7	100	4	3 081.9	50	5
2 833.6	300	40	2 926.5	100	10	3 085.5	70	18
2 836.6	80R	2	2 932.7	400	80	3 087.8	5	70
2 838.2	2	150	2 933.6	400	150	3 092.4	50	15
2 840.4	2	50	2 938.4	50	3	3 093.9	50	15
2 842.8	200	50	2 939.3	200	40	3 095.4	70	18
2 843.5	3	80	2 940.1	100	40	3 101.0	....	100
2 844.5	200	200	2 940.2	150	50	3 103.3	70	15
2 844.8	150	30	2 942.1	150	40	3 110.8	....	70
2 845.4	150	10	2 946.9	150	10	3 112.9	1	50
2 846.8	150	10	2 951.9	400	200	3 113.9	50	35
2 848.1	150	15	2 953.0	30	100	3 115.9	50	18
2 848.5	300	50	2 956.8	1	100	3 117.4	70	10
2 849.8	15	50	2 957.6	100	30	3 125.0	50	20
2 850.5	200	100	2 963.3	300	100	3 127.8	18	100
2 851.0	400	150	2 963.9	50	10	3 129.5	50	7
2 852.4	5	100	2 965.1	40	800	3 129.9	50	8
2 857.3	60	5	2 965.5	150	50	3 130.6	100	35
2 858.4	100	300	2 965.9	30	80	3 132.6	250	25
2 864.5	125	30	2 969.5	150	80	3 135.9	35	100
2 867.4	5	150	2 969.9	50	10	3 137.4	3	50
2 868.7	150	40	2 975.6	200	50	3 141.4	1	50
II 2 868.9	5	60	2 976.3	2	150	3 143.0	10	50
2 871.4	200	50	2 978.2	....	150	3 147.4	70	50
2 873.4	200	40	2 978.8	200R	30	3 148.0	50	7
2 873.6	150	50	2 986.8	20	100	3 150.8	50	35

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

TANTALUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 162.7	70	7	3 311.2P**C	300	70	3 973.2	1	400
3 163.1	70R	35	3 317.9††C	200	25	3 979.3	50	3
3 168.2	....	70	3 318.5	70	3	3 996.2	100	30
3 170.3	250	35	3 318.8	125	35	4 026.9	40	30
3 172.9	50	25	3 325.7	50	3	4 029.9	50	5
3 173.6	70	10	3 331.0	18	200	4 033.1	100	10
3 176.3	70	18	3 332.4	50	3	4 040.9	50	5
3 180.9	100	35	3 337.8	100	18	4 061.4	50	30
3 182.6	70R	18	3 339.9	15	70	4 067.9	100	40
3 184.6	70	18	3 358.5	70	25	4 085.8	5	80
3 191.2	50	5	3 361.6	125	50	4 123.2	50R	4
3 192.3	70	18	3 366.7	50	15	4 129.4	200	40
3 198.7	125	18	3 371.5	70	20	4 136.2	80	30
3 198.9	....	70	3 376.5	15	70	4 175 2	100	40
3 199.2	....	70	3 379.5	18R	50R	4 205.9	100	30
3 206.4	70	15	3 406.7	70	18	4 206.4	50	20
3 207.9	70	15	3 406.9p	70	15	4 268.3	50	15
3 216.9	100	18	3 414.1	18	100	4 279.1	30	10
3 221.3	70	15	3 419.7	50	5	4 286.4	80	20
3 223.8	200	50	3 430.9	50	70	4 303.0	125	40
3 227.3	70	10	3 436.0	70	18	4 355.1	80	10
3 229.2	300	70	3 437.4	7	300	4 386.1	50	15
3 229.9	35	50	3 439.0	....	70	4 402.5	100	20
3 230.9	200	18	3 440.2	18	50	4 415.7	40	10
3 234.7	70	10	3 446.9	2	150	4 441.0	60	2
3 237.8	70	7	3 463.8	50	....	4 441.7	100	2
3 240.0	200	18	3 480.5	70	200	4 480.9	200	10
3 242.0	125	15	I 3 497.8	70	5	4 495.0	50	2
3 242.8	125	10	3 503.9	70	10	4 496.5	100	2
3 245.3	70	2	3 505.0	70	2	4 509.3	60	2
3 248.5	100	3	3 511.0	100	35	4 511.0	200	50
3 250.4	70	3	3 527.1	50	2	4 511.5	300	40
3 256.8	100	1	3 565.6	....	50	4 521.1	200	10
3 259.9	50	3	3 566.7	50	5	4 527 5	150	5
3 260.2	125	18	3 573.4	15	70	4 530 8	300	50
3 263.8	70	2	3 584.2	50	7	4 547.1	150	2
3 269.1	70R	7	3 595.6	70	5	4 552.0	400	8
3 271.2	70	18	3 607.4	70	35	4 553.7	200	2
3 273.1	70	3	3 625 2	70R	2	4 556.4	200	5
3 274.9	200	35	3 626.6	125	18	4 565.9	200	15
3 275.7	70	35	3 642.1	125	18	4 566.9	100	2
3 275.9	50	1	3 731.0	50	3	4 573.4	200	2
3 279.3	50R	3	3 784.3	150	50	4 574.3	300	20
3 287.3	50	....	3 792.0	50	10	4 580.7	200	10
3 292.5	70	3	3 496.2	....	50	4 583.2	150	10
3 293.9	70	10	3 833.7	40	200	4 601.4	60	100
3 295.3	125	20	3 918.5	25	10	4 602 2	100	2
3 299.8	70	10	3 922 4	5	50	4 604 9	200	....
3 302.8	50	1	3 922 8	100	15	4 619 5	300	10
3 304.4	70	15	3 922 9	100	10	4 623 0	50	1
3 309.8	70	5	3 970.1	100	40	4 633 1	150	3

For explanation of control and interfering line symbols see page 415.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

TANTALUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
4 661.1	300	5	5 396.0	80	....	6 268.7	200	....
4 669.1	300	15	5 402.5	80	30	6 281.3	50	....
4 681.9	200	50	5 405.0	80	....	6 309.6	100	....
4 684.9	100	2	5 419.1	80R	....	6 325.0	100	....
4 685.3	80	2	5 431.7	60	....	6 332.9	50	....
4 691.9	400	5	5 435.3	80	....	6 341.2	50	....
4 693.3	150	3	5 461.3	80	....	6 356.1	100	....
4 701.3	150	2	5 490.1	60	....	6 360.8	100	....
4 706.1	200	2	5 494.8	50	....	6 373.1	50	....
4 722.9	200	....	5 499.4	60	....	6 389.4	100	....
4 730.1	100	5	5 518.9	100	....	6 430.8	150	....
4 740.2	100R	100	5 548.3	60	....	6 450.4	200	....
4 756.5	150	10	5 584.0	60	....	6 485.4	500	....
4 769.0	150	5	5 598.8	60	....	6 505.5	100	....
4 780.9	50	200	5 620.7	80	....	6 514.4	200	....
4 812.7	150	5	5 645.9	80	....	6 516.1	200	....
4 819.5	100	....	5 664.9	60	....	6 574.8	200	....
4 825.4	150	....	5 688.2	100	....	6 612.0	300	....
4 832.2	100	....	5 699.2	80	....	6 621.3	200	....
4 846.4	100	2	5 706.3	50	....	6 673.7	200	....
4 852.2	80	2	5 746.7	60	....	6 675.5	400	....
4 871.7	50	1	5 766.6	80	....	6 740.7	80	....
4 884.0	150	3	5 767.9	100	....	6 771.7	100	....
4 904.6	80	2	5 776.8	80	....	6 774.3	100	....
4 907.7	50	1	5 780.0	60	....	6 789.0	50	....
4 915.0	50	1	5 780.7	80	....	6 813.3	200	....
4 920.1	150	3	5 811.1	100	....	6 866.2	200	....
4 921.3	50	2	5 849.7	80	....	6 875.3	200	....
4 923.5	60	1	5 850.0	60	....	6 900.6	80	....
4 926.0	60	2	5 866.6	60	....	6 902.1	150	....
4 936.4	100	....	5 877.4	100	....	6 927.4	150	....
4 968.5	60	1	5 882.3	80	....	6 928.5	150	....
5 012.5	60	....	5 901.9	80	....	6 951.3	100	....
5 037.4	60	....	5 918.9	80	....	6 953.9	50	....
5 043.3	60	....	5 939.8	80	....	6 966.1	150	....
5 067.8	60	....	5 944.0	80	....	6 995.4	200	....
5 076.4	50	....	5 997.2	200	....	7 005.1	50	....
5 087.4	60	....	6 020.7	300R	....	7 007.0	100	....
5 090.7	60	....	6 045.4	200	....	7 025.0	80	....
5 115.8	80	....	6 047.2	150	....	7 081.3	50	....
5 136.5	60	40	6 053.6	150	....	7 125.7	80	....
5 156.6	80	....	6 090.8	50	....	7 148.6	150	....
5 161.8	80	....	6 101.6	150	....	7 172.9	150	....
5 212.7	60	....	6 144.6	50	....	7 250.3	80	....
5 230.8	60	....	6 152.5	60	....	7 301.7	200	....
5 279.8	60	....	6 154.5	200	....	7 346.4	100	....
5 341.0	150	80	6 158.8	80	....	7 352.9	150	....
5 342.3	80	....	6 189.7	50	....	7 357.0	100	....
5 349.1	80	....	6 249.8	100	....	7 369.1	100	....
5 354.7	80R	....	6 256.7	300	....	7 407.9	150	....
5 389.3	100	....	6 266.4	50	....	7 485.9	300	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

TANTALUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
7 814.0	50	....	7 882.4	150	....	7 950.2	50	....
7 842.8	50	....						

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Fe 2692.6	*Ba Cr Fe Mn Mo Te V W	Pt 2650.9	
Mo 2688.0		V 2677.8	
†Be 2348.6	†Ba Fe Pb	‖Cr 2691.1	‖Co Cr Fe Mo Ti
Mo 2644.3		Mo 2775.4	
‡Al 2660.3	‡Al Hg Mo Pb Sb W	¶Fe 2727.5	¶Be Fe In Mn Pt
§Cr 2835.6	§Au Co Sb V W	Mo 2701.4	
A_1Fe 2387.5			**Cr W Ce U Sr Cu Mo
A_2Fe 2689			††Ce Cb V Zr Co Au Ta Y

TELLURIUM

Te

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 000.2	30	....	2 107.6	100	....	I 2 530.7	....	30
2 001.6	600	....	I 2 142.8p	600	....	I 2 769.7	....	30
I 2 002.0	50	....	I 2 147.2	....	150	I 3 175.1	30	15
2 002.7	50	....	I 2 159.8	100	....	4 866.2	....	800
2 039.8	300	....	2 166.9	100	....	5 449.8	....	75
2 070.9	150	....	2 207.2	50	....	5 649.3	....	250
2 074.7	30	....	I 2 208.8	200	....	5 708.1	....	250
I 2 081.0	400	....	I 2 383.3C	500	300	5 755.9	....	250
2 107.2	100	....	I 2 385.8†C	600	....	6 437.1	....	1000

Control lines:	Interfering lines:
†Au 2352.7	†Ir Rh Cr Y Ni
Co 2383.5	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

TERBIUM

Tb

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 540.1	3	50	3 625.5	50	15	4 033.0	125	5
2 658.9	....	500	3 628.2	100	15	4 066.2	40	3
2 885.1	....	70	3 638.5	80	50	4 100.9	50	2
2 891.4	3	500	3 641.7	70	30	4 144.5	80	10
3 078.9	30	80	3 645.4	50	15	4 179.0	50	2
3 147.0	50	3	3 647.8	50	....	4 226.4	50	....
3 218.9	50	50	3 650.4	50	100	4 235.3L	20	1
3 220.0	50	50	3 654.9	70	30	4 276.8	50	2
3 252.3	50	30	3 658.9	100	100	4 278.5	200	100
3 274.2	70	....	3 663.1	50	15	4 318.9	150	30
3 281.4	50	15	3 664.6	50	8	4 325.8	100	....
3 293.1	50	100	3 676.4	100	200	4 326.5	150	4
3 294.0	50	3	3 677.9	70	8	4 338.5	100	3
3 324.4	70	50	3 682.3	50	30	4 342.5	50	....
3 339.0	50	8	3 691.2	50	50	4 353.2	50	....
3 349.2	30	50	3 694.8	50	8	4 356.8	60	....
3 372.7	50	....	3 702.9	50	200	4 367.3	30	....
3 413.8	50	30	3 703.9	70	100	4 393.1	100	....
3 420.3	50	15	3 711.7	200	30	4 423.1	35	....
3 446.4	50	....	3 755.2	50	100	4 493.1	100	....
3 454.1	80	30	3 765.1	70	100	4 511.5	40	....
3 457.0	50	8	3 767.5	75	8	4 563.7	50	....
3 468.0	50	15	3 776.5	100	100	4 578.7	70	....
3 472.8	50	15	3 806.9	50	30	4 642.0	40	....
3 500.3	50	....	3 840.3	50	....	4 645.3	60	....
3 500.8	70	15	3 842.5	40	....	4 702.4	80	....
3 507.5	50	8	3 848.8p	100	200	4 752.2	100	80
3 509.2p	200	200	3 874.2	200	200	4 875.6	20	2
3 510.1	50	8	3 899.2	200	100	5 065.8	40	....
3 519.8	50	15	3 901.4	50	8	5 089.1	40	....
3 523.7	30	50	3 922.7	50	8	5 228.1	40	....
3 525.6	50	8	2 925.5	150	200	5 319.2	40	....
3 531.7	15	50	3 935.3	50	8	5 369.7	40	....
3 540.2	50	50	3 939.6	200	200	5 376.0	40	....
3 543.9	50	15	3 946.9	150	30	5 514.5	50	....
3 546.5	50	8	3 958.0	60	15	5 516.2	50	....
3 561.7p	200	200	3 958.4	100	15	5 685.8	40	....
3 568.5	50	50	3 976.8	150	200	5 747.6	60	....
3 579.2	50	50	3 981.9L	80	200	5 785.2	40	....
3 585.0	15	50	4 002.6	50	5	5 803.1	40	....
3 596.4	50	15	4 005.6	100	125	5 851.1	40	....
3 600.4	8	50	4 031.6	50	3	5 967.3	40	....
3 611.3	50	8						

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

THALLIUM

Tl

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 2 237.9	60R	3	I 2 609.2	400R	200R	I 3 229.8§S_8C	2000	800
2 299.0	30	150	2 665.6S_3	10	3	II 3 261.6	70	300R
I 2 316.0	60R	....	I 2 709.2S_4	400R	200R	I 3 519.2*LS_9C	2000R	1000R
I 2 379.7S_1	100R	200R	I 2 767.9S_5C	400R	300R	I 3 529.4C	1000	800
2 380.3	20	60	I 2 826.2S_6	200R	100R	I 3 653.0	150	50
2 531.6	....	100	I 2 918.3S_7C	400R	200R	I 3 775.7p†		
I 2 552.5	80R	1	I 2 921.5	200R	100R	LS_{10}C	3000	1000R
2 552.7	....	100	I 2 945.0	50	25	I 5 350.5P‡C	5000R	2000R
I 2 580.1S_2	100R	80R	II 3 091.7	.....	50	I 6 549.8	300	50
I 2 609.0	80R	10				I 6 713.7	100	40

Control lines:	Interfering lines:	Control lines:	Control lines:
*Co 3409.2	*Co Cr Cu Fe Mn Rh Zr	S_1Pb 2393.8	S_7Pb 2926.8
Fe 3558.5	Ce N: Bi V	S_2Pb 2577.3	S_8Pb 3240.2
V 3556.8		S_3Pb 2657.2	2657.2
†Ti 3786.0	†Fe Mo Ni Sb Ti	S_4Pb 2697.5	S_9Pb 3220.5
V 3750.9		S_5Pb 2657.2	3262.4
‡Fe 5307.4	‡Al Ba Be Ca Co Cr Cb Ti	S_6Pb 2657.2	S_{10}Pb 3740.0
	W Mn Ta		4019.6
	§Mo Fe Ta Ag Be VCe		

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

THORIUM

Th

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 301.2	....	30	2 822.0	10	10	3 012.7	12	10
2 324.7	....	15	2 824.7	....	25	3 015.7	15	10
2 363.1	....	15	2 826.9	12	12	3 017.1	12	10
2 391.5	....	15	2 832.3	18	25	3 019.4	12	10
2 413.5	5	20	2 837.3*C	15	10	3 022.1	12	12
2 428.0	3	25	2 842.8	12	10	3 025.4	20	5
2 431.7	2	30	2 847.4	10	10	3 026.6	15	15
2 463.7	....	25	2 851.3	10	10	3 028.6	12	12
2 474.0	....	15	2 870.4	18	20	3 034.1	15	15
2 475.3	....	15	2 881.1	10	10	3 035.1	15	15
2 501.1	....	20	2 882.0	10	12	3 038.6	12	12
2 512.7	....	15	2 884.3	12	12	3 040.0	12	10
2 545.1	....	20	2 885.0	12	15	3 043.1	12	12
2 545.3	15	4	2 887.8	18	18	3 045.6	12	15
2 547.9	15	10	2 891.3	10	10	3 047.0	12	20
2 549.5	....	15	2 895.1	10	10	3 049.1	20	20
2 554.7	....	15	2 896.7	....	20	3 049.9	10	10
2 564.4	....	20	2 897.1	12	5	3 051.0	10	10
2 565.6	10	15	2 898.9	....	25	3 051.8	10	10
2 566.6	15	10	2 899.7	15	12	3 058.4	10	10
2 567.8	....	20	2 908.4	12	12	3 060.2	12	15
2 589.1	20	10	2 910.6	12	10	3 061.7	12	15
2 597.1	20	5	2 917.4	25	6	3 063.0	25	25
2 600.6	....	15	2 919.8	10	10	3 065.9	12	10
2 600.9	15	4	2 925.1	10	15	3 070.8	12	10
2 623.5	10	10	2 928.3	12	12	3 078.8	10	25
2 641.5	15	10	2 932.5	....	25	3 080.2	12	25
2 658.7	15	10	2 936.2	10	10	3 082.2	10	10
2 681.0	....	25	2 936.5	12	12	3 083.3	12	15
2 684.3	15	15	2 942.9	10	10	3 088.0	10	10
2 686.2	....	40	2 971.5	10	10	3 088.5	20	20
2 687.1	10	10	2 974.0	10	10	3 089.6	10	10
2 692.4	20	20	2 976.0	15	10	3 090.1	15	10
2 704.0	15	15	2 978.6	1	100	3 098.0	1	50
2 708.2	10	20	2 980.3	15	10	3 100.9	12	12
2 716.3	10	10	2 982.0	150	5	3 102.7	15	12
2 729.3	10	12	2 983.8	10	10	3 105.1	10	10
2 734.4	10	10	2 985.2	15	12	3 105.8	15	20
2 752.2	15	12	2 988.2	15	20	3 106.7	12	10
2 763.6	10	10	2 991.1	15	10	3 107.0	15	15
2 768.8	15	15	2 993.8	12	15	3 108.3	15	20
2 770.8	10	10	2 997.0	10	10	3 110.0	15	15
2 771.5	10	10	2 999.1	12	12	3 111.8	20	8
2 778.7	10	10	3 000.9	30	10	3 112.4	....	20
2 783.1	10	10	3 001.3	12	12	3 115.7	10	10
2 791.0	10	10	3 002.4	15	12	3 116.5	10	10
2 794.3	10	10	3 006.9	12	15	3 117.6	12	12
2 797.7	10	10	3 008.5	15	12	3 119.5	15	15
2 819.3	12	10	3 009.7	15	10	3 123.0	20	20

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

THORIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spar
3 124.4	12	15	3 280.4	10	12	3 615.1	10	10
3 125.5	10	10	3 286.6	10	12	3 621.1	10	10
3 127.2	10	20	3 287.7	12	15	3 639.4	10	10
3 131.1	12	10	3 290.6p¶C	....	40	3 649.3	10	10
3 133.6	10	10	3 291.7	10	12	3 650.8	10	10
3 134.4	10	12	3 292.5	10	12	3 652.2	10	10
3 139.3	10	15	3 293.9	10	10	3 652.5	10	10
3 141.8	12	10	3 295.3	10	10	3 656.2	10	10
3 142.8	12	12	3 295.5	10	10	3 658.1	10	10
3 146.0	12	15	3 297.8	10	12	3 659.5	10	12
3 148.0	3	40	3 300.5	....	30	3 663.7	10	10
3 150.5	12	15	3 304.2	15	3	3 673.3	10	10
3 151.6	10	10	3 310.2	8	15	3 673.8	10	10
3 154.3	15	12	3 313.7	4	50	3 675.6	10	10
3 154.7	15	15	3 314.8	10	10	3 678.0	10	10
3 155.8	12	10	3 320.3	10	12	3 679.7	12	12
3 156.3	12	10	3 321.5	10	12	3 788.8	12	12
3 162.8	10	10	3 324.8	10	10	3 690.1	10	10
3 164.4	10	10	3 325.1	10	15	3 690.5	10	10
3 169.3	12	10	3 334.6	10	15	3 698.3	12	10
3 174.2	10	10	3 339.6	....	20	3 700.8	15	10
3 175.7	12	15	3 351.2	10	15	3 706.8	15	10
3 179.0	10	10	3 358.6	10	12	3 711.3	30	20
3 180.2	15	15	3 367.8	8	12	3 712.5	15	8
3 181.2	10	10	3 377.4	....	20	3 717.8	20	10
3 182.6	10	10	3 392.0	10	15	3 718.2	15	10
3 184.9	10	10	3 421.2	10	10	3 719.4	30	10
3 198.2	10	10	3 434.0	12	12	3 720.3	15	10
3 208.0	18	10	3 436.0	12	10	3 721.8	40	30
3 210.3	10	10	3 439.0	10	12	3 722.2	35	25
3 213.6	12	10	3 439.7	10	12	3 724.7	30	20
3 216.6	3	20	3 452.7	10	10	3 726.7	30	20
3 217.5	10	10	3 462.9	10	12	3 727.9	15	5
3 220.3	12	10	3 463.7	10	12	3 730.4	15	3
3 221.3	15	40	3 465.8	10	10	3 738.8	20	20
3 225.4	12	15	3 468.2	10	12	3 739.8	20	5
3 226.4	10	10	3 469.9	12	15	3 740.8	40	20
3 229.0	12	15	3 473.0	10	10	3 741.2†C	80	80
3 230.9	15	12	3 476.5	10	10	3 742.2	20	10
3 232.1	3	25	3 478.1	10	10	3 742.9	20	8
3 235.8	12	12	3 479.2	15	10	3 744.7	15	10
3 238.1	12	15	3 482.6	10	10	3 746.0	15	20
3 240.5	10	10	3 486.5	12	12	3 750.1	20	5
3 241.1	10	12	3 493.5	30	15	3 752.6	40	50
3 245.8	12	15	3 501.5	10	10	3 754.0	20	5
3 249.9	10	10	3 521.9	10	10	3 754.6	20	10
3 262.7	12	15	3 537.2	10	10	3 756.3	50R	20R
3 267.0	10	12	3 538.8p	....	50	3 759.3	20	10
3 269.5	10	10	3 559.5	10	10	3 760.2	20	5
3 273.9	10	15	3 601.1p	8	10	3 761.1	15	8
3 275.0	10	12	3 609.4	12	10	3 762.9	20	20

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

THORIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 763.3	15	8	3 863.4	20	20	4 025.6	20	20
3 765.3	20	10	3 872.7	30	20	4 034.3	10	10
3 767.9	20	15	3 884.8	20	15	4 036.6	15	15
3 771.4	30	20	3 893.4	15	10	4 041.2	20	10
3 773.8	20	20	3 895.4	20	10	4 050.9	15	5
3 775.3	20	5	3 900.9	30	30	4 063.4	10	10
3 775.9	20	10	3 902.1	10	10	4 069.2	40	30
3 777.1	40	20	3 903.1	15	5	4 085.0	15	15
3 777.9	15	10	3 904.1	20	20	4 086.5	12	12
3 778.8	15	10	3 905.2	30	30	4 094.8	15	15
3 779.8	20	10	3 912.3	15	15	4 098.9	10	10
3 780.5	20	10	3 913.0	15	15	4 100.8	18	18
3 780.9	20	5	3 915.2	15	1	4 104.4	10	10
3 781.0	15	3	3 916.7	15	10	4 105.3	12	12
3 781.7	20	10	3 927.2	15	10	4 108.4	15	15
3 783.0	20	20	3 927.4	15	10	4 116.7	12	15
3 783.3	20	15	3 929.7	30	20	4 132.8	10	12
3 785.7	15	15	3 932.2	15	10	4 134.1	10	10
3 786.9	15	15	3 937.0	15	10	4 140.2	15	15
3 787.2	40	20	3 937.9	15	10	4 142.5	10	10
3 789.1	20	20	3 938.7	15	10	4 142.7	10	10
3 793.5	20	8	3 943.7	10	10	4 148.2	10	10
3 793.8	20	8	3 945.5	20	15	4 150.0	10	12
3 794.2	10	10	3 946.2	20	20	4 156.5	10	10
3 794.3	10	10	3 949.0	30	30	4 162.7	10	12
3 795.4	20	10	3 950.4	30	30	4 164.3	10	10
3 795.8	20	10	3 951.5	20	20	4 165.5	20	10
3 803.1	15	15	3 956.6	10	10	4 170.5	10	10
3 805.8	20	15	3 956.7	10	10	4 171.3	10	12
3 807.9	10	10	3 960.3	10	15	4 178.1	10	12
3 808.1	10	10	3 963.5	10	10	4 208.9	15	15
3 809.2	15	12	3 972.2	15	8	4 248.0	15	12
3 811.4	20	10	3 976.4	15	20	4 249.7	12	10
3 813.1	15	20	3 979.1	10	10	4 250.3	12	10
3 814.6	15	15	3 981.1	20	20	4 256.1	12	10
3 817.4	20	10	3 988.0	50	30	4 273.4	20	15
3 817.7	15	15	3 988.9	10	10	4 276.8C	10	8
3 820.8	20	20	3 992.3	10	10	4 277.3	20	12
3 821.4	15	15	3 994.6	30	10	4 281.1	20	10
3 822.1	10	10	3 996.1	15	10	4 281.4C	15	10
3 823.1	20	10	3 997.9	10	10	4 282.0	30	25
3 824.3	20	20	4 001.1	10	5	4 283.5	10	10
3 824.8	20	10	4 003.1	10	10	4 310.0	15	12
3 829.4	40	20	4 003.3	15	15	4 320.1	12	10
3 833.0	20	10	4 005.5	20	30	4 327.1	15	7
3 834.6	15	10	4 006.4	10	10	4 335.8	10	10
3 836.5	50	50	4 007.0	20	20	4 361.3	12	10
3 839.7	15	15	4 011.8	15	15	4 374.8	15	10
3 842.0	20	20	4 012.5	15	15	4 381.9§	30	30
3 845.0	20	10	4 019.1p‡C	8	8	4 391.1‖C	50	40
3 854.5	20	20	4 022.1	20	15	4 416.2	15	8

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

THORIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spa
4 433.0	25	15	4 863.2C	20	10	5 539.9	18	4
4 439.1	20	15	4 872.9	20	....	5 548.2	15	...
4 440.6	15	6	4 882.5	5	20	5 707.1	20	5
4 440.9	20	10	4 919.8C	50	20	5 720.2	18	...
4 465.3	30	15	4 921.6	20	....	5 815.4	18	2
4 480.8	25	10	4 987.1	15	4	5 989.0	20	5
4 487.5	20	10	5 017.2	50	10	6 112.8	15	3
4 488.7	25	12	5 028.6	40	10	6 120.5	15	3
4 496.3	12	10	5 049.8	30	5	6 261.1	15	2
4 510.5	30	20	5 198.8	15	....	6 274.1	25	3
4 537.1	20	8	5 247.7	20	3	6 279.2	20	2
4 593.6	....	50	5 277.5	15	3	6 342.9	15	....
4 631.8	15	10	5 325.1	15	3	6 457.3	15	....
4 651.6	30	15	5 390.5	18	5	6 462.6	30	....
4 723.8	12	10	5 415.4	20	3	6 531.3	15	....
4 740.5	20	15	5 425.7	15	3	6 989.7	20	....
4 752.4	20	12	5 435.9	15	2	7 168.9	15	....
4 761.1	10	12						

Control lines:	Interfering lines:
*Cr 3605.3	*Al Au Cd Cu Fe Mn Pt Sb Sn W
Sn 2863.3	
†Fe 3749.5	†Cu Fe Mn Mo Pb Ti
Fe 3787.9	
Pb 3572.7	
Ti 3752.9	
‡Co 4086.3	‡Co Cr Fe Mn Mo Ni Ti V W Pb Ir Ce U
	¶Fe Mo Mn Cu Ca Ce Pt

Control lines:	Interfering lines:
Mn 4048.8	
§Cr 4371.3	§Al Bi Co Cr Fe Ga Mo Ni Pb
Fe 4045.8	
Mo 4277.3	
‖Pb 4245.2	‖Al Bi Co
Ti 4427.1	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

THULIUM

Tm

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 338.4	2	50	II 3 145.3	25	60	3 744.1	100	10
2 357.0	3	80	3 151.0	200	200	3 751.8	50	5
2 361.2	1	60	3 157.3	200	150	3 761.3	250	150
2 406.6	2	60	3 168.2	25	60	3 761.9	200	120
2 480.1	60	20	3 172.8	200	200	3 795.8	250	150
2 489.5	2	100	3 173.6	50	100	3 817.4	60	15
2 509.1	80	40	3 210.6	40	50	3 838.2	80	60
2 519.8	1	50	3 212.0	50	40	3 848.0	400	250
2 561.7	60	30	3 235.5	80	40	3 883.1	100	10
2 588.3	40	80	3 236.8	100	80	3 883.4	150	30
2 607.1	50	30	3 240.2	100	80	3 887.3	80	8
2 624.3	80	40	3 241.5	150	125	3 900.8	80	50
2 679.6	30	50	3 249.8	10	50	3 916.5	80	8
2 721.2	60	100	3 258.0	125	60	3 929.6	70	50
2 744.1	20	50	3 261.7	30	100	3 949.3	50	5
2 785.1	60	30	3 266.6	70	50	3 958.1	200	40
2 794.6	60	20	3 267.4	50	40	3 995.6	100	....
2 797.3	60	100	3 269.0	40	150	3 996.5	200	40
2 827.0	20	50	3 291.0	125	80	4 094.2	300	30
2 827.9	50	100	3 302.5	125	80	4 105.8	300	30
2 769.2	100	300	3 309.8	80	60	4 138.4	80	8
2 890.9	60	15	3 310.6	60	20	4 187.6	300	30
2 918.3	25	50	3 316.9	60	20	4 199.9	100	20
2 925.7	20	60	3 354.9	30	50	4 203.7	250	25
2 926.7	80	60	3 362.6	250	200	4 242.2	500	100
2 936.0	80	300	3 374.5	60	30	4 359.9	300	30
2 951.3	30	150	3 397.5	100	50	4 386.4	200	10
2 959.7	20	60	3 400.0	50	40	4 481.3	400	50
2 965.9	50	100	3 425.1	200	300	4 519.6	50	1
2 981.5	60	100	3 425.6	100	50	4 522.6	200	300
2 986.5	50	150	3 430.0	100	100	4 529.4	80	5
2 990.5	80	30	3 431.2	50	50	4 555.3	25	50
3 015.3	125	100	3 441.5	150	80	4 556.7	35	70
3 026.1	60	30	3 453.7	150	80	4 561.8	50	10
3 042.5	50	....	3 462.2	250	200	4 599.0	80	....
3 050.7	50	150	3 535.5	80	25	4 615.9	200	300
3 054.1	30	60	3 536.2	40	60	4 626.3	50	20
3 056.1	40	100	3 536.6	60	20	4 626.6	50	3
3 073.1	60	150	3 565.9	40	50	4 634.2	80	10
3 073.5	25	60	3 566.5	60	20	4 677.9	50	2
3 073.9	15	50	3 608.8	100	20	4 681.9	50	2
3 087.0	30	60	3 643.7	60	40	4 733.3	80	5
3 093.1	30	60	3 668.1	80	20	4 831.2	50	80
3 097.0	15	50	3 678.9	50	40	4 957.2	50	5
3 098.6	80	60	3 700.3	150	80	5 009.8	50	50
3 099.6	10	50	3 701.4	150	80	5 034.2	100	100
3 131.3	400	500	3 717.9	100	10	5 307.1	100	20
3 133.9	200	200	3 725.1	60	15	5 331.4	80	10
3 144.9	25	60	3 734.1	150	50	5 675.8	100	100

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

THULIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
5 684.8	40	80	6 657.7	70	10	7 490.2	100	....
5 764.3	50	....	6 721.4	60	20	7 558.4	200	....
5 895.6	80	20	6 779.8	300	50	7 731.6	150	....
6 431.0	15	60	6 844.3	250	30	7 856.1	60	....
6 460.3	400	80	6 845.8	200	20	7 927.5	50	....
6 605.0	300	60	7 481.1	100	....	7 930.9	100	....

TIN

Sn

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 039.5	....	200	2 558.0	30	6	I 3 262.3p§	400	300
2 041.2	10	....	2 571.6$S_{12}G_3N_6$	100	125	LB$_4$C		
2 113.9	25R	5R	2 594.4S_1	60	80	II 3 283.5	....	100
I 2 148.7	50R	20	2 637.0S_2	15	15	3 330.6$S_{16}N_{13}$	100	100
II 2 151.5	....	10	2 661.2S_3	100	80	3 352.4	....	100
2 152.5	30	....	2 706.5A_1S_9	200R	150R	3 655.8S_6	30	25
2 194.5	30R	60	N_7C			3 801.0S_7N_9	200	150
2 199.3	30	60R	2 761.8S_4G_4	10	10	4 511.3	200	....
II 2 209.7$S_{22}N_1$	25	60R	2 779.8	80	100	I 4 524.7pN_{10}	500	50
2 231.7	30	60	2 785.0	60	60	4 585.6	....	25
2 246.1	100R	100R	2 787.9	50	50	II 5 332.2	....	20
2 251.2	25	50	2 813.6	50	50	II 5 562.0	....	40
2 267.2	15	10	I 2 840.0*LS_8	300R	300R	II 5 588.9	2	50
2 268.9	100R	100R	N_8C			5 631.7	50	200
2 282.2S_{20}	10	15	2 850.6S_5B_1	80	100	5 970.3	10	30
2 286.7	60	40	I 2 863.3p†S_{24}	300R	300R	6 037.7	12	50
2 317.2	100R	100R	N_9B_2C			6 054.9	12	30
2 334.8S_{14}	100R	100R	2 913.5	100	125	6 068.9	12	25
2 354.8S_{25}	150R	150R	I 3 009.1pS_{21}	300	20	6 149.7	15	50
G_1N_2			$N_{10}B_3C$			6 154.6	12	25
2 380.7S_{15}	10	10	3 032.8	50	20	6 171.5	10	10
2 408.2	30	30	I 3 034.1p‡S_{11}	200	150	6 310.8	10	8
2 421.7S_{13}	150R	200R	$N_{11}C$			II 6 453.6	6	300
G_2N_3			3 067.8	10	15	6 462.4	4	300
2 429.5N_4	200R	250R	3 141.8S_{17}	20	30	6 579.3	....	15
II 2 483.4	125	125	I 3 175.1‖pL	500	400R	I 7 685.3	20	....
2 495.7	100	100	$S_{10}N_{12}C$			I 7 755.0	100	....
2 523.9	60	60	3 218.7S_{18}	18	50	I 7 808.2	10	....
2 531.1	40	15	3 223.7S_{19}	10	15	7 910.5	10	....
2 546.6$S_{23}N_5C$	100	100						

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

TIN (*Continued*)

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Cr 2835.6	*Al Cr Fe Mn Mo Ph Ir U Na V	W 2896.4	
Ti 3202.5		‡Fe 3047.6	‡As Au Bi Co Cr K
†Fe 2863.9	†Bi Fe Mn Mo Sb Ce V Rh	V 3188.5	
As 2780.2		V 3187.7	
Cr 2849.8	‖ Ce Ta Fe Th Co Mn	§Fe 3268.2	§Ba Cd Fe Mo Pb Th Ta Os V
Cr 2865.1		Cd 2288.0	

Control lines	
A$_1$Zn	2684.2
S$_1$Pb	2614.2
	2562.4
S$_2$Pb	2614.2
Bi	2627.9
S$_4$Pb	2823.2
	2873.3
	2802.0
Bi	2696.8
S$_5$Pb	2833.1
	2802.0
	2938.3
	2898.0
S$_6$Pb	4057.8
Cd	3404.7
	3467.7
S$_{19}$Cd	3467.7
Bi	3067.7
S$_{20}$Cd	2288.0
S$_{21}$Bi	3067.7
Bi	2898.0
Cu	2938.3
S$_{22}$Pb	2218.1
S$_{23}$Pb	2562.4
S$_{24}$Cu	2858.3
	2882.8
Bi	2938.3
S$_{25}$Cu	2356.5
G$_1$Pb	2388.8
G$_2$Pb	2411.7
G$_3$Pb	2628.3

Control lines:	
	3466.2
	3610.5
	3614.4
S$_7$Pb	4057.8
S$_8$Pb	2657.2
S$_9$Pb	2717.2
	2628.3
S$_{10}$Pb	3176.5
Bi	3067.7
S$_{11}$Pb	3043.9
	3036.1
S$_{12}$Pb	2657.2
	2628.3
	2562.4
S$_{13}$Pb	2411.8
	2388.8
G$_4$Pb	2629
	2657
N$_1$Pb	2218.1
N$_2$Sn	2317.2
Pb	2399.6
	2388.6
N$_3$Sn	2880.7
Pb	2411.9
	2399.6
N$_4$Sn	2380.7
N$_5$Pb	2562.4
N$_6$Pb	2657.2
N$_7$Pb	2657.2
	2628.3
N$_8$Sn	2850.6
N$_9$Sn	2913.5
	2850.6

Control lines:	
	2399.6
Cu	2406.7
S$_{14}$Pb	2332.5
S$_{15}$Pb	2399.6
S$_{16}$Cd	3403.7
S$_{17}$Cd	3403.7
Bi	2938.3
	3067.7
	3024.6
S$_{18}$Cd	3403.7
	3466.2
	3467.7
Bi	3019
	3067.7
S$_{19}$Cd	3403.7
	3466.2
Cu	2913.5
N$_{10}$Sn	2913.5
Pb	3043.9
	2973.0
N$_{11}$Sn	2913.5
Pb	3119.2
N$_{12}$Pb	3119.2
N$_{13}$Pb	3119.2
N$_{14}$Pb	3786.2
N$_{15}$Pb	5042.7
B$_1$Pb	2802.0
B$_2$Cu	2766.4
Pb	2873.3
B$_3$Cu	2961.2
B$_4$Cu	2766.4
Cu	3274.0
Fe	3268.3

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

TITANIUM

Ti

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 154.7	3	60	II 2 828.2	2	200	II 3 078.6C	60	500R
II 2 348.0	....	20	II 2 828.9	....	150	II 3 088.0C	70	500R
I 2 378.1	10	....	II 2 836.6	....	100	II 3 089.4	12	100
I 2 418.4	20	....	II 2 839.8	....	100	II 3 090.1	....	100
I 2 421.3	25	1	II 2 841.9	40	125	II 3 097.2	20	150
I 2 424.2	30	1	II 2 846.1	....	70	II 3 103.8	20	200
II 2 450.4	10	100	II 2 851.1	20	80	II 3 105.1	12	100
II 2 478.6	....	50	II 2 856.2	....	100	II 3 106.2	25	150
2 517.4	20	30	2 857.8	....	70	3 110.7	10	100
II 2 524.6	15	60	2 862.0	....	100	II 3 112.1	7	70
II 2 525.6	35	125	2 870.0	....	100	II 3 117.7	15	200
II 2 531.3	30	125	II 2 877.4	30	100	II 3 119.8	4	150
II 2 534.6	25	80	II 2 884.1	35	125	II 3 130.8	25	100
II 2 535.9	20	60	2 888.6	....	70	II 3 143.8	18	125
I 2 599.9	70	10	2 890.6	....	50	II 3 148.0	25	150
I 2 605.2	100	12	II 2 891.1	20	50	II 3 152.3	30	125
I 2 611.3C	80	15	2 906.7	....	100	II 3 154.2	20	100
I 2 619.9	35	7	I 2 912.1	35	15	II 3 161.2	30	125
I 2 632.4	50	7	2 913.3	....	50	II 3 161.8	35	150
II 2 638.7	....	100	2 916.1	....	50	II 3 162.6	50	200R
I 2 641.1C	150	20	II 2 926.8	....	50	3 164.9	1	50
II 2 642.2	....	150	II 2 931.3	....	150	II 3 168.5	70	300R
I 2 644.3C	100	12	II 2 936.2	....	100	II 3 174.8	....	100
II 2 646.1	....	200	II 2 938.7	....	100	II 3 181.8	....	50
I 2 646.6C	20	15	I 2 942.0C	100	150	I 3 186.5	150	80
I 2 662.0	35	5	II 2 943.1	....	60	II 3 190.9	40	200R
I 2 669.6	60	12	II 2 945.5	....	100	I 3 192 0	100	20
I 2 679.9	100	12	I 2 948.3C	100	30	I 3 199.9‡C	200	150
2 698.5	....	200	II 2 954.8	....	150	II 3 202.5	25	200
II 2 716.3	5	70	I 2 956.1C	125	25	II 3 214.8	20	80
I 2 733.3	60	15	II 2 959.0	....	150	II 3 217.1	40	150
I 2 739.8	50	3	I 2 967.2	35	8	II 3 218.3	15	150
II 2 742.3	30	40	2 977.8	....	50	II 3 222.8	20	150R
II 2 746.7	....	150	II 2 979.2	....	100	II 3 224.2	15	150
II 2 751.7	....	200	II 2 990.2	....	80	II 3 228.6	30	100
II 2 752.9	....	50	2 995.8	10	70	II 3 229.2	30	60
I 2 758.1	70	4	II 3 017.2	15	200	II 3 229.4	15	70
II 2 764.8	15	70	II 3 022.8	....	150	II 3 232 3	30	100
II 2 780.6	....	60	II 3 023.9	....	100	II 3 234 5*C	100	500R
II 2 786.0	....	60	II 3 029.7	12	150	II 3 236 6C	70	300R
II 2 788.0	....	70	II 3 043.9	3	50	II 3 239.0C	60	300R
II 2 800.6	....	150	3 045.1	2	50	II 3 239 7	25	80
I 2 802.5	100	15	II 3 046.7	10	60	II 3 242 0C	60	300R
II 2 805 0	....	200	II 3 056.7	12	70	I 3 248 6	25	200
II 2 810.3	6	150	II 3 058.1	12	70	II 3 251.9	50	150
II 2 817.9	10	200	II 3 071.2	12	70	II 3 252 9	60	200R
II 2 820 0	....	70	II 3 072.1	25	125	II 3 254 3	35	125
II 2 821 4	....	70	II 3 073 0	35	200R	II 3 261 6	70	300
II 2 827.2	....	80	II 3 075 2	40	300R	II 3 263.7	10	70

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

TITANIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 3 271.7	35	125	II 3 510.8	40	125	I 3 929.9	70	35
II 3 272.1	25	100	II 3 535.5	15	125	I 3 947.8	70	35
II 3 275.3	8	50	II 3 596.1	50	125	I 3 948.7	80	40
II 3 276.8	12	70	I 3 598.7	70	30	I 3 956.3	100	50
II 3 278.3	25	100	I 3 610.2	100	70	I 3 958.2	150	100
II 3 278.9	40	150	II 3 624.8	60	125	I 3 962.9	80	35
II 3 282.3	30	150	I 3 635.5p	200	100	I 3 964.3	80	40
II 3 287.7	40	200	II 3 641.3	60	150	I 3 981.8	100	70
I 3 292.1	70	40	I 3 642.7p	300	125	I 3 982.5	80	30
I 3 299.4	50	35	I 3 646.2	70	25	I 3 989.8	150	100
I 3 308.4	50	10	I 3 653.5p	500	200	I 3 998.6§	150	100
II 3 308.8	35	100	I 3 654.6	100	40	I 4 003.8	50	70
I 3 309.5	60	25	I 3 658.1	150	60	I 4 008.1	50	7
II 3 315.3	12	100	II 3 659.8	50	150	I 4 008.9	80	35
II 3 318.0	60	125	I 3 660.6	90	18	I 4 009.7	60	25
II 3 321.7	15	125	II 3 662.2	40	100	II 4 012.4	35	50
II 3 322.9	80	300R	I 3 669.0	100	40	I 4 013.6	70	7
II 3 326.8	15	125	I 3 671.7	150	70	I 4 015.4	70	10
II 3 229.5	80	200R	II 3 685.2	157	700R	I 4 017.8	70	8
II 3 332.1	40	125	I 3 689.9	100	40	I 4 021.8	100	20
II 3 335.2	60	150	I 3 694.4	80	20	I 4 024.6	80	35
II 3 337.9	12	60	3 700.1	60	5	I 4 026.5	70	10
II 3 340.3	80	100	I 3 702.3	60	20	II 4 028.3	20	80
I 3 341.9C	100	300R	I 3 704.3	70	25	I 4 030.5	80	18
II 3 343.8	60	70	II 3 706.2	30	125	I 4 035.8	50	5
II 3 346.7	60	60	I 3 707.5	100	10	I 4 055.0	80	30
II 3 349.0PC	125	800R	I 3 708.6	50	3	I 4 058.1	50	6
II 3 349.4†	100	400R	I 3 710.0	80	25	I 4 060.3	60	25
I 3 354.6	100	20	I 3 717.4	80	50	I 4 064.2	50	15
II 3 361.2‡	100	600R	II 3 721.6	60	125	I 4 065.1	80	35
I 3 361.3	80R	50R	I 3 722.6	100	60	I 4 078.5	125	50
I 3 370.4C	80	15	I 3 724.6	100	50	I 4 082.5	60	25
I 3 371.5C	100	15	I 3 725.2	150	60	I 4 112.7	70	20
II 3 372.8L	80	400R	I 3 729.8	500	150	I 4 127.5	70	15
¶¶C			I 3 740.1	150R	40	4 137.3	50	15
II 3 380.3	25	150R	II 3 741.6	30	200	I 4 159.6	60	15
II 3 383.8B	70	300R	I 3 752.9	200	80	II 4 163.7	35	150
I 3 385.9	80	25	I 3 753.6	80	35	II 4 171.9	15	70
3 387.8	60	125	II 3 759.3L	100	400R	I 4 180.9	100	20
II 3 394.6	70	200	II 3 761.3L	100	300R	I 4 186.1	100	40
II 3 402.4	15	90	I 3 771.7	70	30	I 4 203.5	50	10
II 3 407.2	12	50	II 3 776.1	8	60	I 4 249.1	60	3
II 3 417.0	7	50	I 3 789.3	50	15	I 4 256.0	80	15
II 3 444.3	60	150	I 3 868.4	50	8	I 4 258.5	70	7
II 3 452.5	12	100	I 3 882.9	35	10	I 4 261.6	70	8
II 3 456.4	25	125	I 3 895.2	70	10	4 263.1	125	35
II 3 461.5	80	125	II 3 900.5	30	50	I 4 270.1	50	3
II 3 465.6	6	60	I 3 904.8	70	35	I 4 274.6	100	40
II 3 477.2	60	100	3 913.5	40	70	I 4 276.4	50	20
II 3 483.8	....	70	I 3 914.3	50	10	I 4 278.2	50	15
II 3 504.9	20	150	3 924.5	70	35	I 4 281.4	80	20

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

TITANIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 4 282.7	70	25	I 4 479.7	70	35	I 4 856.0	100	10
I 4 286.0	100	40	I 4 481.3	100	60	I 4 868.3	100	8
I 4 287.4	100	50	II 4 488.3	10	125	I 4 870.1	100	18
I 4 289.1	125	50	I 4 489.1	100	40	I 4 885.1	150	25
II 4 290.2	35	60	4 496.1	60	60	I 4 899.9	150	20
I 4 290.9	70	30	II 4 501.3	60	100	II 4 911.2	12	100
II 4 294.1	60	80	I 4 512.7	100	60	I 4 913.6	125	15
I 4 295.8	100	40	I 4 518.0	100	60	I 4 921.8	100	5
I 4 298.7	125	50	I 4 522.9	100	70	I 4 928.3	100	4
I 4 299.2	70	20	I 4 527.3	100	50	I 4 938.3	70	2
I 4 299.6	60	10	I 4 533.2¶	150	40	I 4 975.4	80	4
II 4 300.0	40	100	I 4 534.8**	100	40	I 4 978.2	70	3
I 4 300.6	125	20	I 4 535.6††	80	50	I 4 981.7p	300	125
I 4 301.1C	150	50	I 4 535.9‡‡	40	20	I 4 989.1	100	4
I 4 305.9‖	300	150	I 4 536.1§§	40	20	I 4 991.1p	200	100
II 4 307.9	100	100	I 4 544.7	150	60	I 4 997.1	50	4
II 4 312.9	35	100	I 4 548.8	125	25	I 4 999.5p	200	80
I 4 314.8	100	20	II 4 549.6	100	200	I 5 001.0	80	2
I 4 318.6	100	50	4 552.5	150	50	I 5 007.2p	200	40
4 321.7	70	25	I 4 555.5	125	60	I 5 009.6	50	2
I 4 325.1	100	40	I 4 559.9	50	5	I 5 013.3	80	7
I 4 326.4	60	25	II 4 563.8	100	200	I 5 014.2	100	30
II 4 337.9	70	125	II 4 572.0	150	300	I 5 016.2	100	15
II 4 344.3	12	50	II 4 590.0	40	100	I 5 020.0	100	80
I 4 360.5	60	15	I 4 617.3	200	100	I 5 022.9	100	18
II 4 386.9	8	80	I 4 623.1	125	40	I 5 024.8	100	15
I 4 393.9	60	12	I 4 629.3	70	7	I 5 025.6	100	8
II 4 395.0	50	150	I 4 639.4	80	18	I 5 035.9	125	30
II 4 399.8	40	100	I 4 640.0	60	15	I 5 036.5	125	25
I 4 404.3	50	30	I 4 645.2	100	10	I 5 038.4	100	20
II 4 411.1	7	100	I 4 650.0	60	4	I 5 040.0	125	25
I 4 416.5	70	10	I 4 656.5	150	70	I 5 052.9	50	3
I 4 417.3	80	20	I 4 667.6	150	8	I 5 064.7	150	35
II 4 417.7	40	80	I 4 675.1	50	5	I 5 066.0	50	2
I 4 421.8	60	15	I 4 681.9	200	100	I 5 087.1	70	1
I 4 422.8	80	25	I 4 691.3	125	25	I 5 113.4	80	2
I 4 426.1	80	25	I 4 698.8	100	20	I 5 120.4	100	4
I 4 427.1	125	60	I 4 710.2	100	25	I 5 145.5	100	4
I 4 434.0	100	50	I 4 722.6	80	8	I 5 147.5	90	3
I 4 440.3	80	35	I 4 731.2	50	6	II 5 152.1	....	50
II 4 443.8	80	125	I 4 742.8	100	40	I 5 152.2	90	2
I 4 449.1	150	80	I 4 758.1	125	60	I 5 173.7	125	20
I 4 450.9	150	60	I 4 759.3	100	8	II 5 188.7	80	100
I 4 453.3	150	70	II 4 780.0	10	100	I 5 193.0	150	25
I 4 453.7	80	40	I 4 792.4	70	12	I 5 210.4	200	35
I 4 455.3	150	80	I 4 799.8	80	15	I 5 219.7	60	2
I 4 457.4	150	100	II 4 805.1	15	125	I 5 223.6	50	1
I 4 465.8	100	40	I 4 805.4	70	4	I 5 224.3	70	8
II 4 468.5	80	150	I 4 820.4	125	30	I 5 225.0	90	6
I 4 471.2	100	40	I 4 840.9	125	25	II 5 226.6	30	50
I 4 474.9	80	30	I 4 848.5	60	2	I 5 238.6	50	100

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

TITANIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 5 255.8	40	80	I 5 762.3	70	50	I 6 261.1	300	100
I 5 266.0	70	3	I 5 766.4	70	50	I 6 303.8	200	....
I 5 283.5	50	2	I 5 774.1	70	50	I 6 312.2	80	....
I 5 295.8	50	1	I 5 786.0	100	60	I 6 318.0	50	....
I 5 297.3	70	2	I 5 804.3	100	50	I 6 336.1	80	....
II 5 336.8	18	30	I 5 866.5	300	400	I 6 366.4	80	....
I 5 351.1	50	60	I 5 880.3	60	125	I 6 546.3	80	....
I 5 397.1	60	....	I 5 899.3	150	150	II 6 552.6	200	....
I 5 409.6	50	1	I 5 918.6	80	....	I 6 554.2	125	150
I 5 477.7	70	2	I 5 922.1	100	100	I 6 556.1	150	....
I 5 488.2	30	30	5 932.1	80	....	I 6 565.6	50	....
5 490.2	70	2	I 5 937.8	60	....	I 6 599.1	100	....
I 5 503.9	60	3	I 5 941.8	100	....	6 743.1	100	....
I 5 512.5	125	12	I 5 953.2	150	250	I 6 861.5	50	....
I 5 514.3	70	10	I 5 965.8	150	200	I 7 038.8	100	....
I 5 514.5	80	15	I 5 978.6	125	150	I 7 209.4	150	....
I 5 565.5	80	2	I 5 999.7	70	....	I 7 216.2	50	....
I 5 644.1	150	200	I 6 064.6	80	20	I 7 244.9	150	....
I 5 648.6	80	60	I 6 085.2	100	60	I 7 251.7	125	....
I 5 662.2	100	100	I 6 091.2	125	25	I 7 299.7	50	....
I 5 662.9	40	....	I 6 098.7	60	....	I 7 318.4	80	....
I 5 675.4	90	125	I 6 126.2	150	60	I 7 344.7	200	....
I 5 679.9	50	....	I 6 146.2	400	....	7 357.7	200	....
I 5 689.5	80	80	I 6 215.3	100	50	7 364.1	150	....
I 5 702.7	60	40	I 6 220.5	100	30	I 7 440.6	100	....
I 5 708.2	30	....	I 6 221.4	80	....	I 7 489.6	150	....
I 5 711.9	50	40	I 6 258.1	200	100	I 7 949.2	50	....
I 5 715.1	70	60	I 6 258.7	300	250	I 7 978.9	100	....
I 5 739.5	70	80						

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Ni 3057.6	*Cr Cu Fe Mn Mo Ni	††Co 4092.4	††Al Be Co Cr Cu Fe
†Mn 3350.4	†Ca Co Cu Mn Mo Sc Sr Cb Cr Rb Cs	Cr 4526.5	
‡Mo 3447.1	‡Ca Co Cr Mo Ni Sc Te	‡‡Cr 4526.5	‡‡Al Be Co Cr Mn Mo
§Co 4092.4	§Co Fe Ga Mn Mo	§§Cr 4526.5	§§Al Be Cr Cu Mn Mo
**Ca 4318.6	**Ba Bi Ca Cd Co Cr Fe	B_1Cr 3368.1	
	‖ U Sr Y Ni V Te Co Ce		
	¶¶ Ce Zr Co Pd Pt Y Ca Cb Rh		

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

TUNGSTEN

W

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 008.1	12	25	II 2 245.2	10	20	II 2 446.4	10	30
2 015.8	6	20	II 2 248.3	12	15	2 448.2	....	15
2 016.4	4	20	II 2 248.8	20	25	2 448.4	15	5
2 022.0	4	15	2 260.1	15	3	II 2 449.7	2	15
II 2 026.1	7	25	2 263.5	7	25	II 2 451.5	15	20
II 2 030.0	10	30	II 2 270.2	12	20	2 452.0	12	15
2 037.6	3	18	2 277.6	20	10	2 454.7	15	40
II 2 054.7	9	20	II 2 294.5	20	20	2 455.0	15	10
II 2 065.6	10	20	II 2 303.8	10	15	2 456.5	15	5
II 2 071.2	10	25	II 2 326.1	10	15	2 458.6	1	15
2 075.6	10	20	2 331.3	15	....	2 459.3	18	10
2 078.4	6	25	II 2 337.7	8	20	II 2 459.9	....	15
2 079.1	12	30	2 358.8	10	20	2 462.8	15	10
2 088.2	12	30	2 360.4	15	5	2 464.0	2	15
2 089.1	10	20	2 363.1	15	5	2 464.3	15	2
2 092.1	....	25	2 364.2	5	15	II 2 464.6	3	20
2 093.8	8	15	2 369.0	....	15	2 465.2	12	20
II 2 094.7	10	18	2 370.0	5	25	2 465.6	....	20
2 098.3	10	20	II 2 370.6	2	18	II 2 466.5	12	20
2 098.6	10	20	2 383.0	15	3	2 466.8	15	7
2 100.7	10	25	II 2 390.4	10	20	2 468.4	....	20R
2 105.8	6	20	II 2 392.9	8	15	II 2 470.8	5	20
2 106.2	10	20	II 2 397.1p	18	30	2 471.7	1	15
2 110.3	10	25	II 2 401.9	2	15	2 472.5	15	5
II 2 116.9	8	15	2 402.4	15	20	2 474.1	20	10
II 2 118.9	10	20	2 404.2	10	15	2 475.6	1	20
2 135.0	....	20	2 405.3	10	15	II 2 477.8	15	30
II 2 138.2	10	25	2 405.7	15	8	2 480.1	25	10
2 152.1	3	20	2 407.8	1	15	2 480.9	20	3
2 156.4	5	25	2 408.3	3	15	2 481.4	25	3
2 160.9	....	30	2 409.2	....	15	II 2 484.0	2	15
2 163.9	12	25	2 409.5	....	15	2 484.4	2	15
II 2 166.3	10	30	2 410.4	....	20	2 484.7	20	6
2 169.5	15	5	II 2 411.8	2	15	2 486.3	15	2
II 2 173.5	10	15	2 414.8	....	25	2 487.5	15	5
II 2 186.7	8	15	2 415.7	15	9	2 488.8	10	20
2 194.5	10	15	2 418.3	....	15	II 2 489.2	10	20
II 2 204.5	12	30	2 419.3	2	20	II 2 492.9	6	25
II 2 206.6	10	15	2 420.5	2	15	2 495.3	20	5
2 214.8	10	20	2 423.3	....	15	II 2 496.6	10	20
2 215.3	6	15	2 423.9	....	15	II 2 497.5	10	15
II 2 216.0	10	15	2 424.2	20	7	2 499.2	2	15
II 2 219.7	15	4	2 426.5	1	20	2 499.4	10	1
II 2 220.9	8	18	II 2 435.0	3	30	II 2 499.7	10	15
II 2 225.9	10	18	2 436.0	30	10	2 506.0	10	15
II 2 229.6	10	20	II 2 440.4	2	15	II 2 510.0	1	15
II 2 237.1	10	15	2 443.6	15	8	II 2 510.5	3	15
2 239.8	....	18	2 444.1	18	9	2 513.5	....	15
2 241.1	10	15	2 444.9	....	15	2 518.1	6	15

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

TUNGSTEN (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 519.9	15	2	2 624.5	1	15	II 2 716.3	8	20
2 520.5	15	10	2 633.1	15	12	2 717.2	4	15
2 521.3	15	2	II 2 633.9	1	15	II 2 718.0	10	20
II 2 522.0	10	20	2 634.6	1	20	2 718.9	25	20
2 528.9	3	15	II 2 635.4	3	18	2 719.3	15	20
2 531.0	9	15	II 2 637.6	6	15	II 2 720.4	4	18
2 534.1	2	15	II 2 643.1	12	15	2 721.7	9	15
II 2 534.8	2	15	2 643.3	2	20	2 724.6C	10	8
2 537.1	1	15	2 646.2	15	10	II 2 729.6	10	25
2 542.6	1	15	2 647.7	10	20	2 729.9	1	15
2 545.3	15	9	II 2 653.6	10	15	2 733.2	15	9
2 547.1	20	10	2 656.5	15	5	2 734.8	10	20
2 553.2	12	15	II 2 658.0C	10	20	2 736.6	....	15
2 554.7	4	15	2 662.8	15	10	2 737.4	....	20
II 2 554.9	15	10	II 2 664.3	10	20	2 740.8	5	25
II 2 555.1	10	15	2 666.1	....	15	2 742.5	5	25
2 560.1	15	8	II 2 666.5	8	20	2 742.9	3	25
2 563.2	8	30	2 667.7	....	15	II 2 745.0	2	25
2 563.9	7	15	II 2 669.3	15	30	2 746.7	12	20
II 2 567.6	7	15	2 670.4	3	15	2 752.2	2	20
2 568.8	2	15	2 671.5	15	5	II 2 753.1	15	10
II 2 569.3	15	25	2 673.6	7	20	2 760.7	8	20
II 2 571.4	15	30	II 2 677.8	8	20	II 2 761.6	10	25
2 573.5	15	....	2 678.9	20	10	2 762.3	20	10
2 576.2	2	20	2 681.4	20	18	II 2 764.3	20	60
II 2 576.4	2	15	2 685.0	2	15	2 766.3	....	20
2 576.9	....	15	2 687.0	4	20	II 2 768.3	10	20
2 577.0	15	4	2 687.4	15	3	2 769.0	18	10
2 579.3	2	20	II 2 688.2	8	20	2 769.7	15	10
II 2 579.5	8	25	2 690.7	....	15	2 770.9	25	12
II 2 581.2	7	20	2 691.1	15	8	2 772.5	10	60
2 584.4	15	10	II 2 694.4	9	18	2 774.5	15	20
II 2 586.0	8	20	2 694.6	....	18	II 2 776.5	12	25
2 586.9	75	30	2 695.7	20	12	2 778.7	3	20
II 2 589.2pB$_1$C	15	25	2 696.9	....	18	II 2 780.3	10	20
2 594.5	4	15	2 697.5	15	3	II 2 782.1	4	30
2 595.6	2	20	II 2 697.7	15	25	II 2 785.6	3	20
II 2 596.9	1	15	2 699.6	15	10	II 2 786.3	2	15
II 2 598.7	12	20	2 700.0	15	10	II 2 790.4	2	15
II 2 601.4	2	15	2 700.3	15	....	II 2 799.0	8	20
2 602.0	15	6	II 2 701.5	2	18	II 2 801.1	6	15
2 602.5	10	25	2 702.1	8	25	II 2 805.9	9	30
II 2 603.0	5	15	II 2 703.1	3	15	2 808.9	1	15
2 612.2	10	15	2 703.5	2	20	2 812.3	3	20
2 613.8	15	9	II 2 706.7	6	20	2 818.1	15	20
II 2 615.4	6	20	2 707.0	6	15	2 819.1	2	15
2 618.1	....	15	2 708.6	10	15	II 2 822.6	12	30
2 620.2	15	15	II 2 709.6	6	15	2 829.8	15	10
2 622.2	15	10	2 712.7	1	20	2 830.1	4	20
II 2 623.1	2	20	II 2 715.3	8	20	2 831.4C	25	10
2 623.9	....	15	2 715.5	20	8	2 833.6	15	12

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

TUNGSTEN (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 834.2	....	30	3 180.0	6	20	II 3 613.8p	10	30
2 847.1	2	15	3 187.1	....	20	3 617.5	35	20
2 848.0	15	12	3 197.6	....	20	3 628.4	3	20
2 852.1	1	18	3 198.3	1	15	3 628.9	....	15
2 853.5	12	15	3 201.6	7	20	3 631.9	15	10
2 859.5	3	15	II 3 203.3	4	20	II 3 641.4	12	40
2 866.1	15	10	II 3 206.4	6	15	II 3 645.6	4	20
II 2 868.7	6	25	3 210.0	2	25	II 3 646.5	10	35
II 2 886.9	3	20	3 215.3	....	15	II 3 657.6	10	25
2 889.8	2	20	II 3 243.3	5	20	II 3 657.9	5	15
2 896.4C	15	25	II 3 251.2	10	18	3 672.6	1	18
2 903.5	....	15	3 262.3	....	18	3 682.1	25	20
II 2 904.1	3	18	3 300.8	15	12	3 691.9	4	20
II 2 925.0	2	15	3 304.5	10	20	3 694.5	10	20
2 925.8	....	15	3 308.3	3	25	3 707.9	20	20
2 935.0	15	12	3 311.4	15	12	3 708.5	3	35
2 936.7	10	20	II 3 317.4	1	15	3 712.2	....	18
II 2 940.2	4	18	3 326.2	15	12	II 3 716.1	8	18
2 944.4*C	30	20	3 331.7	15	12	3 722.2	12	15
2 947.0†C	20	18	II 3 338.6	5	15	3 741.7	12	20
2 950.4	....	20	II 3 342.5	10	30	3 742.7	15	12
II 2 952.3	12	30	II 3 345.9	10	15	3 745.6	....	25
II 2 987.3	8	15	3 348.3	2	15	3 756.9	6	15
II 3 000.6	4	20	II 3 358.6	10	40	3 757.9	15	20
II 3 002.3	1	15	II 3 361.1	10	15	3 758.9	....	15
II 3 010.8	8	20	3 366.7	....	15	3 760.1	15	10
II 3 022.0	15	20	II 3 376.1	9	40	3 768.4	20	18
II 3 024.5	9	20	II 3 379.0	4	15	3 773.7	20	18
3 024.9	15	12	3 383.1	....	18	3 774.1	....	18
3 033.6	12	15	II 3 401.9	7	40	3 780.8	20	18
II 3 036.7	8	20	3 410.2	....	15	3 792.8	15	15
II 3 039.6	2	20	3 416.6	7	20	3 803.7	....	15
II 3 051.3	10	30	3 421.1	3	20	3 809.2	25	20
II 3 063.4	....	20	3 424.4	2	15	3 810.4	15	15
II 3 064.0	2	20	II 3 440.6	5	20	3 817.5	18	15
II 3 069.3	6	15	II 3 449.9	6	25	3 824.4	12	15
3 077.5	2	40	3 455.0	....	20	3 835.0	15	20
3 095.9	2	20	3 460.4	....	15	3 838.5	15	20
II 3 100.7	2	20	3 463.3	10	15	3 846.2	20	20
II 3 103.5	2	15	II 3 463.5	8	25	3 847.5	18	15
3 111.1	9	15	3 475.3	....	25	3 860.0	15	30
II 3 149.8	10	15	II 3 490.9	7	15	3 868.0	30	35
3 151.3	5	20	3 495.2	12	20	3 872.8	12	10
3 152.5	10	15	II 3 529.6	10	20	3 881.4	20	20
3 155.1	10	20	3 536.3	3	15	3 897.9	12	15
3 163.4	12	15	II 3 549.1	5	25	3 900.9	....	15
3 169.9	10	15	3 570.7	15	15	II 3 935.4	7	20
3 170.2	15	9	II 3 572.5	10	35	3 937.0	12	15
II 3 175.9	8	20	II 3 592.4	9	35	3 980.6	12	15
II 3 177.2	8	25	3 596.2	....	15	3 983.3	12	25
II 3 178.0	8	20	3 611.9	....	20	4 001.9	....	15

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

TUNGSTEN (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
I 4 008.8P‡C	45	45	4 361.8	20	9	4 613.3	50	10
4 015.2	25	30	4 364.8	25	12	4 620.6	20	7
4 019.2	18	15	4 372.5	25	10	4 634.8	20	7
4 044.3	15	12	4 384.9	25	15	4 641.8	20	6
4 045.6	12	15	4 389.8	15	6	4 642.6	30	8
4 064.8	15	12	4 394.1	20	9	4 646.1	15	3
4 070.6	15	12	4 404.0	20	9	4 657.4	50	12
4 074.4§C	50	45	4 408.3	25	12	4 659.9	200	70
4 081.3	2	25	4 412.2	20	10	4 662.0	15	2
4 083.0	12	15	4 415.1	15	6	4 668.5	20	3
4 095.7	12	15	4 420.5	30	10	4 676.6	20	2
4 102.7	35	30	4 425.9	15	6	4 677.7	25	3
4 109.8	20	20	4 436.9	30	12	4 679.0	15	2
4 142.3	15	9	4 438.3	15	7	4 680.5	150	40
4 145.2	15	8	4 441.8	20	10	4 683.5	20	10
4 154.7	15	10	4 445.2	20	6	4 693.7	50	12
4 157.0	3	25	4 449.0	20	6	4 698.6	15	1
4 168.7	10	15	4 455.5	15	5	4 700.4	50	4
4 170.5	15	7	4 456.1	15	5	4 702.5	15	5
4 171.2	25	12	4 458.1	15	5	4 706.2	15	1
II 4 175.6	7	25	4 460.5	25	7	4 711.2	15	3
4 203.8	15	6	4 463.5	15	7	4 712.5	18	5
4 204.4	20	10	4 466.3	20	10	4 720.4	15	3
4 207.1	25	12	4 466.7	20	10	4 725.1	40	3
4 219.4	25	15	4 481.3	15	6	4 729.7	30	15
4 222.1	15	8	4 484.2	35	20	4 745.6	25	1
4 226.9	15	3	4 494.0	15	7	4 757.5	60	10
4 234.4	25	7	4 494.5	20	12	4 757.8	15	1
4 241.4	30	10	4 495.3	20	6	4 758.2	15	1
4 244.4	40	20	4 504.9	30	10	4 773.9	30	2
4 258.5	15	5	4 512.9	30	10	4 787.9	15	1
4 259.4	30	20	4 513.3	30	10	4 788.4	15	1
4 263.3	25	15	4 529.8	15	4	4 797.5	15	2
4 266.5	15	8	4 530.5	15	4	4 799.9	50	10
4 269.4	40	30	4 534.7	15	5	4 807.4	15	1
4 269.8	15	10	4 535.1	15	5	4 835.0	15	....
4 274.6	20	12	4 536.7	15	6	4 843.8	50	12
4 275.5	15	10	4 542.9	15	3	4 854.1	30	....
4 276.7	15	10	4 543.5	25	10	4 858.6	15	....
4 286.0	15	8	4 546.5	30	10	4 878.3	30	....
4 294.1	20	10	4 551.9	35	10	4 886.9	50	10
I 4 294.6p‖C	50	50	4 556.9	15	5	4 888.4	20	....
I 4 302.1p¶C	60	60	4 563.6	15	5	4 890.3	15	....
4 303.3	....	15	4 570.7	30	10	4 892.4	25	....
4 306.9	20	15	4 586.8	30	5	4 902.3	15	....
4 316.8	15	7	4 588.8	40	15	4 916.2	20	....
4 332.1	15	7	4 592.4	20	10	4 931.6	30	....
4 335.6	2	15	4 592.6	15	5	4 948.6	15	....
4 347.0	20	7	4 600.0	50	10	4 953.1	25	....
II 4 348.1	50	40	4 600.4	20	4	4 972.6	15	....
4 355.2	15	9	4 609.9	50	10	4 977.2	15	....

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

TUNGSTEN (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
4 979.8	25	....	5 243.0	25	1	5 675.4	15	....
4 982.6	40	5	5 254.5	18	....	5 697.8	35	....
4 983.5	20	....	5 255.4	20	....	5 723.1	15	....
4 984.2	15	....	5 259.4	20	....	5 735.1	50	25
4 984.7	15	....	5 263.2	15	....	5 749.2	15	....
4 986.9	40	1	5 275.6	20	....	5 793.1	20	....
4 989.1	15	....	5 318.9	20	....	5 796.5	20	....
4 994.1	30	....	5 337.4	15	....	5 804.9	25	12
5 002.8	15	10	5 348.9	30	....	5 839.0	25	....
5 006.2	40	7	5 350.4	18	....	5 845.3	18	....
5 007.2	15	2	5 351.9	20	....	5 851.6	25	....
5 013.5	15	....	5 368.7	15	....	5 856.6	15	....
5 015.3	40	5	5 388.0	15	....	5 864.6	20	....
5 039.0	15	1	5 435.1	20	....	5 880.2	15	....
5 040.4	35	1	5 456.6	18	....	5 902.7	20	....
5 053.3	60	10	5 475.1	15	....	5 947.6	15	....
5 054.6	25	3	5 477.8	25	20	5 965.9	25	....
5 055.5	20	....	5 486.0	20	....	5 972.5	25	....
5 069.1	50	3	5 487.8	15	....	6 012.8	30	3
5 071.7	40	3	5 492.3	50	50	6 021.5	25	....
5 105.5	15	....	5 500.5	15	15	6 081.5	25	1
5 110.4	20	....	5 503.5	45	1	6 128.3	15	2
5 138.4	20	....	5 514.7	50	8	6 153.7	15	1
5 145.8	18	....	5 531.5	18	....	6 154.9	15	1
5 184.0	20	....	5 533.3	25	....	6 203.5	15	1
5 192.7	30	....	5 568.1	15	....	6 285.9	30	2
5 203.3	30	....	5 631.3	15	....	6 292.0	30	2
5 204.5	40	....	5 632.0	15	....	6 404.2	25	2
5 206.2	30	....	5 642.0	15	....	6 708.2	20	....
5 212.8	20	5	5 648.4	50	50			
5 224.7	50	8	5 674.4	30	....			

Control lines:		Interfering lines:
*Fe	2912.2	*Ba Co Fe Ga Mn Mo
Ga	4033.0	
Ti	2956.1	
†Fe	2936.9	†Cr Hg Mo
Cb	3225.5	
Mn	2605.7	
‡Ti	4024.6	‡Co Fe Mn Mo Ni
§Fe	4063.6	§Cr Cu Fe Mn Mo

Control lines:		Interfering lines:
‖Fe	4132.1	‖Al Cr Fe Mn Mo Ni
Mo	4292.1	
Ti	4298.7	
V	4291.8	
¶Ca	4226.7	¶Bi Ca Co Cr Fe
Fe	4132.1	
B$_1$Mn	2593.7	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

URANIUM

U

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 219.3	15	2	2 675.1	15	10	2 844.5	2	12
2 237.4	....	15	2 675.9	15	10	2 845.0	18	8
2 248.0	....	25	2 683.3	25	25	2 847.3	15	4
2 273.4	....	15	2 684.0	15R	10	2 849.5	18	15
2 276.1	....	20	2 691.0	15	30	2 850.5	8	12
2 282.8	....	25	2 695.5	12	30	2 852.8	15	15
2 283.7	....	15	2 698.1	20	50	2 853.4	12	12
2 306.9	....	25	2 707.0	15	20	2 853.6	15	10
2 318.5	....	25	2 713.5	....	15	2 855.6	12	8
2 324.8	2	20	2 725.9	12	12	2 858.9	35	25
2 349.6	....	15	2 730.1	2	15	2 860.5	35	30
2 351.9	....	20	2 730.3	18	8	2 860.8	15	12
2 378.2	....	35	2 731.3	15	8	2 861.1	10	15
2 397.2	....	20	2 734.0	10	15	2 862.4	15	10
2 406.4	10	10	2 739.4	10	10	2 864.3	18	12
2 412.7	4	15	2 743.4	....	20	2 865.1	10	10
2 423.7	15	4	2 744.4	12	10	2 865.7	30	50
2 484.0	15	4	2 746.2	25	6	2 871.0	18	20
2 484.2	10	15	2 748.5	18	15	2 874.1	15	10
2 489.8	12	15	2 750.0	10	12	2 875.2	18	12
2 500.9	18	12	2 751.9	2	20	2 880.5	12	15
2 513.3	1	20	2 754.2	20	35	2 882.7	18	20
2 519.0	15	6	2 755.1	10	12	2 886.4	15	6
2 521.8	5	15	2 759.0	10	10	2 887.3	25	25
2 538.4	15	6	2 762.9	15	20	2 889.6	30	50
2 556.2	15	12	2 764.2	10	10	2 894.1	12	15
2 561.6	12	6	2 765.4	10	10	2 894.5	15	15
2 562.9	15	6	2 766.9	10	10	2 901.2	12	10
2 565.4	30	30	2 770.0	10	12	2 906.8	15	50
2 572.6	....	15	2 789.1	12	10	2 906.9	18R	15
2 577.3	18	6	2 793.9	25	30	2 908.3	12	30
2 587.1	6	15	2 795.2	18	12	2 909.3	6	15
2 591.3	18	12	2 801.7	10	10	2 914.0	14	4
2 593.6	18	6	2 802.6	15	30	2 914.3	18	25
2 597.7	25	15	2 807.1	18	30	2 914.6	12	15
2 608.2	25	6	2 810.0	20	20	2 921.7	10	15
2 609.3	15	2	2 811.3	35	30	2 924.6	10	10
2 628.9	15	10	2 813.0	12	12	2 925.6	15	25
2 632.9	15	8	2 818.0	18	30	2 927.4	12	10
2 633.0	5	15	2 819.8	6	25	2 928.6	15	35
2 635.5	25	50	2 821.1	20	35	2 930.8	4	30
2 641.9	18	8	2 822.7	10	10	2 931.4	12	12
2 645.5	20	25	2 824.3	25	30	2 932.6	10	25
2 649.1	15	15	2 826.2	18	12	2 936.5	12	20
2 651.8	3	15	2 828.9	18	20	2 941.9	15	30
2 652.8	12	10	2 832.1	35	50	2 943.9	10	25
2 660.1	15	10	2 833.8	15	25	2 954.4	12	15
2 664.2	18	20	2 839.9	18	20	2 954.8	10	15
2 672.7	12R	6	2 842.1	15	12	2 955.6	12	10

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

URANIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 956.1	10	60	3 104.2	20	20	3 342.7	10	10
2 960.9	15	25	3 111.6	15	15	3 361.7	15	8
2 964.2	6	15	3 115.9	8	15	3 363.4	12	3
2 966.1	15	25	3 119.3	10	10	3 371.3	8	15
2 967.9	15	20	3 124.9	12	10	3 375.8	12	10
2 971.1	12	12	3 126.2	12	20	3 378.2	15	1
2 977.3	10	10	3 129.7	8	15	3 386.1	6	15
2 982.7	12	12	3 130.6	....	15	3 390.4	18	10
3 009.4	15	2	3 139.6	25	25	3 399.0	15	....
3 017.0	15	12	3 141.5	5	15	3 403.5	10	10
3 019.3	8	15	3 142.6	12	10	3 412.4	12	12
3 021.2	10	15	3 145.6	12	10	3 422.4	18R	15R
3 022.2	12	12	3 147.1	12	15	3 423.1	12	15
3 024.4	25R	20R	3 149.2	18	18	3 424.6	20	15
3 024.5	18	15	3 153.1	12	15	3 429.0	18R	12
3 025.0	12	20	3 156.1	6	15	3 430.5	12R	5
3 027.7	15	8	3 157.9	10	15	3 435.5	15	....
3 028.2	10	10	3 159.8	8	15	3 436.8	12	15
3 029.1	20	15	3 165.3	6	18	3 443.0	15	....
3 030.8	12	12	3 167.1	10	10	3 486.3	5	15
3 032.0	15	15	3 176.2	20	15	3 488.8	8	15
3 033.2	12	12	3 177.3	15	18	3 489.4	20	1
3 036.0	15	8	3 179.8	12	10	3 490.2	12	20
3 037.9	....	20	3 185.7	12	10	3 493.3	6	15
3 039.3	15	12	3 188.3	10	10	3 496.4	8	15
3 043.8	15	8	II 3 189.2	10	20	3 499.3	6	15
3 044.2	12	10	3 190.7	12	12	3 500.1	15	2
3 046.8	6	15	3 200.1	15	15	3 505.1	8	15
3 047.6	15	20	3 206.0	12	10	3 509.7	10	15
3 048.6	15	8	3 224.3	10	12	3 514.6	18	5
3 050.2	12	8	3 226.2	10	10	3 516.9	6	15
3 051.1	15R	10R	3 229.5	18	25	3 523.6	4	15
3 053.3	....	15	3 232.2	12	12	3 528.7	6	15
3 057.9	20	20	3 250.3	10	10	3 531.1	8	20
3 061.6	12	10	3 261.7	15	10	3 531.6	15	1
3 062.5	12	15	3 263.1	25	8	3 533.6	10	20
3 072.8	20	20	3 265.8	25	18	3 540.4	6	15
3 073.8	15R	10R	3 270.1	20	25	3 546.4	1	15
3 080.0	10	10	3 285.2	12	10	3 547.2	10	12
3 080.7	12	12	3 288.2	25	20	3 550.8	12	20
3 084.2	15	12	3 291.3	12	10	3 552.2C	8	12
3 089.0	20	15	3 293.6	30	5	3 553.4	15	....
3 091.3	15R	12R	3 297.9	6	18	3 555.3	15	6
3 093.0	20	20	3 300.7	15	8	3 561.8	12	30
3 094.8	10	10	3 303.6	10	12	3 565.8	1	15
3 095.0	12	12	3 305.9	10	12	3 566.6	30	10
3 095.2	10	10	3 311.7	10	12	3 569.1	12	20
3 095.7	10	10	3 313.9	10	10	3 577.1	15	3
3 098.0	10	10	3 322.1	18	12	3 581.8	6	15
3 099.0	12R	4	3 337.8	12	10	3 582.0	6	15
3 102.4	12	10	3 341.7	12	15	3 584.9	30	12

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

URANIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 590.3	5	15	3 773.4	20	10	3 881.5	30	20
3 591.6	4	15	3 776.0	10	12	3 882.4	18	18
3 595.0	8	15	3 779.0	8	15	3 883.3	10	18
3 599.8	6	18	3 780.7	15	20	3 884.7	8	20
3 609.0	18	10	3 782.8	25	30	3 887.4	20	....
3 609.7	15	12	3 783.8	20	25	3 887.7	20	10
3 620.1	15	2	3 785.4	....	15	3 890.4	35	30
3 622.7	15	1	3 793.1	12	18	3 891.1	10	10
3 623.1	12	15	3 793.3	20	12	3 891.8	18	1
3 626.0	5	15	3 793.6	10	12	3 892.4	10	12
3 630.7	8	20	3 796.5	10	15	3 892.7	20	30
3 633.3	8	15	3 796.8	12	15	3 893.8	10	10
3 635.4	15	10	3 798.8	15	1	3 894.1	30	4
3 639.5	25	....	3 801.1	20	....	3 895.3	12	20
3 640.8	8	20	3 802.0	15	....	3 896.8	20	25
3 641.0	8	20	3 804.9	12R	4	3 897.1	8	18
3 644.2	18	2	3 808.9	20	....	3 897.3	15	5
3 645.0	8	15	3 809.9	15	2	3 901.6	15	....
3 652.1	12	8	3 811.5	15	....	3 902.6	18	18
3 654.9	25	....	3 811.6	15	....	3 904.3	8	15
3 657.3	6	15	3 812.0	18	6	3 904.9	8	15
3 659.2	15	1	3 812.6	15	4	3 911.7	18	18
3 662.3	10	10	3 813.8	20	15	3 914.3	10	18
3 662.7	15R	2	3 814.1	25	15	3 914.7	12	8
3 668.0	15	8	3 816.6	10	10	3 915.2	15	1
3 670.1*	15	18	3 822.0	15	....	3 915.9	20	30
3 672.6	8	15	3 822.6	12	12	3 923.1	15	6
3 676.6	3	15	3 825.0	15	....	3 924.3	15	15
3 678.8	6	15	3 829.8	15	....	3 926.2	30	6
3 680.9	20	1	3 831.5	25	25	3 928.8	15	....
3 682.0	6	15	3 831.9	15	3	3 931.0	12	35
3 685.8	15	1	3 833.0	20R	15	3 931.5	25	6
3 693.7	4	18	3 836.5	6	15	3 932.0	35	50
3 700.6	12	18	3 837.3	15	....	3 935.4	15	18
3 701.5	10	25	3 839.6	30	2	3 940.5	10	15
3 716.1	18	....	3 843.0	12	12	3 942.8	20	8
3 722.7	10	10	3 844.0	10	10	3 943.8	35	5
3 725.7	3	15	3 844.2	8	15	3 944.1	8	15
3 729.8	8	15	3 851.7	15	2	3 946.7	15	10
3 738.0	8	20	3 854.2	20	....	3 947.5	10	10
3 748.7	15	25	3 854.7	20	30	3 952.9	15	....
3 751.7	10	12	3 859.6†	20	30	3 953.6	6	15
3 752.7	6	15	3 860.6	1	15	3 954.7	20	30
3 754.3	6	12	3 865.9	20	25	3 955.4	8	15
3 759.2	15	15	3 871.0	30	1	3 957.8	10	15
3 760.8	10	15	3 871.4	3	20	3 962.8	15	8
3 763.3	12	25	3 874.0	15	15	3 963.2	10	10
3 765.3	18	1	3 875.3	12	6	3 964.7	10	10
3 768.8	15	12	3 876.1	15	2	3 966.6	20	30
3 769.5	4	18	3 879.5	18	....	3 973.9	15	4
3 772.8	6	20	3 879.7	20	3	3 978.8	8	18

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

URANIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 983.9	5	15	4 141.2	20	30	4 301.5	15	15
3 985.8	25	30	4 146.6	15	....	4 304.1	15R	1
3 988.0	8	12	4 154.0	15	5	4 306.8	40R	4
3 988.9	12	15	4 155.4	12	18	4 313.1	20	1
3 990.4	18	20	4 156.7	15	8	4 313.9	15	10
3 995.0	8	20	4 162.4	18	3	4 316.5	15	1
3 996.0	10	8	4 163.7	10	10	4 325.9	10	10
3 998.2	5	18	4 169.1	20	2	4 328.7	20	1
4 002.3	10	18	4 171.6	30	30	4 341.7	50	50
4 004.1	15	20	4 173.0	10	15	4 347.2	18	18
4 005.7	25	3	4 174.2	12	12	4 355.7	10	20
4 009.2	8	15	4 179.0	15	12	4 362.1	30	3
4 011.5	8	10	4 189.3	10	10	4 362.3	15	18
4 017.7	25	25	4 204.4	15	10	4 371.8	18	1
4 019.0	25	15	4 206.4	10	10	4 372.6	15	18
4 026.0	25	25	4 209.5	15	1	4 372.8	18	5
4 033.4	12	10	4 210.4	10	15	4 373.4	12	12
4 033.7	12	12	4 210.9	12	12	4 382.3	18	5
4 039.8	15	2	4 211.6	18	....	4 387.3	15	4
4 042.8	40	10	4 211.7	10	10	4 393.6	40	6
4 044.4	18	25	4 212.3	12	10	4 399.6	15	6
4 047.6	18	3	4 213.9	20	4	4 408.0	12	12
4 050.0	25	35	4 214.4	10	10	4 413.1	15	4
4 051.9	20	25	4 222.4	18	8	4 415.2	12	12
4 054.3	12	15	4 228.8	18	12	4 418.5	15	....
4 062.5	12	18	4 231.7	25	....	4 423.0	12	10
4 063.1	15	1	4 232.0	15	15	4 426.7	18	15
4 067.8	12	20	4 234.5	18	15	4 426.9	20	1
4 071.1	15	25	4 239.7	10	10	4 427.7	12	15
4 074.5	10	10	4 240.6	10	10	4 433.9	15	12
4 077.8	15	6	4 241.7p§C	40	50	4 440.4	10	12
4 088.3	25	18	4 244.4	25	25	4 440.7	20	20
I 4 090.1C	25	40	4 246.3	30	2	4 460.9	12	10
4 095.7	18	25	4 252.4	15	20	4 462.3	15	18
4 096.4	20	5	4 266.3	15	....	4 463.0	18	30
4 098.0	12	12	4 267.3	12	10	4 465.1	20	25
4 099.3	20R	1	4 267.9	15	4	4 472.3	50	80
4 101.9	18	1	4 268.9	12	10	4 477.7	20	25
4 103.1	18	1	4 269.3	20	30	4 490.8	18	25
4 106.9	25	10	4 274.0	12	15	4 510.3	20	30
4 113.1	12	12	4 276.5	10	12	4 515.3	25	40
4 116.1	25	35	4 280.7	18	3	4 516.7	15	1
4 122.4	15	4	4 282.0	30	30	4 538.2	25	40
4 124.0	20R	1	4 287.9	15	18	4 543.6	50	80
4 124.7	30	25	4 288.8	20	2	4 545.6	20	25
4 125.1	15	1	4 289.9	12	12	4 549.9	12	20
4 128.3	18	20	4 290.9	15	15	4 552.0	15	1
4 133.5	15	....	4 293.3	18	5	4 555.1	20	40
4 136.8	15	8	4 295.1	15	1	4 559.6	15	....
4 138.7	10	10	4 295.3	10	10	4 567.7	20	40
4 139.1	10	10	4 297.1	18	18	4 568.2	4	18

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

URANIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
4 569.9	25	40	4 885.1	18	....	5 836.0	30	....
4 573.7	30	40	4 899.3	25	25	5 837.7	30	1
4 579.6	12	15	4 910.3	15	1	5 845.3	20	....
4 581.7	8	18	4 928.4	20	1	5 870.9	15	....
4 584.8	10	15	5 008.2	30	25	5 915.4	125	....
4 601.1	18	25	5 027.4	40	4	5 971.5	50	....
4 603.7	25	40	5 160.3	18	20	5 976.3	50	....
4 605.1	12	25	5 164.2	15	1	5 986.1	25	....
4 609.9	15	20	5 184.6	12	15	5 997.3	25	....
4 611.4	12	25	5 204.3	10	10	6 077.3	40	....
4 618.4	5	20	5 247.7	12	10	6 171.9	30	....
4 620.2	25	12	5 257.0	15	18	6 293.3	15	....
4 622.4	12	18	5 278.2	12	15	6 359.3	30	....
4 627.1	30	60	5 280.4	30	4	6 372.5	50	....
4 631.6	30	3	5 308.5	25	3	6 379.6	15	....
4 641.7	10	15	5 311.9	18	18	6 389.8	18	....
4 646.6	25	40	5 475.7	20	18	6 392.8	20	....
4 663.8	18	3	5 480.3	15	25	6 395.4	100	....
4 666.9	25	40	5 481.2	30	25	6 449.2	100	....
4 669.3	8	15	5 482.5	12	18	6 465.0	25	....
4 671.4	20	30	5 493.0	60	50	6 503.6	15	....
4 685.7	10	18	5 504.1	12	10	6 518.9	15	....
4 689.1	30	40	5 511.5	30	2	6 555.0	15	....
4 702.5	10	20	5 527.8	25	40	6 620.5	15	....
4 722.7	40	50	5 564.2	40	3	6 826.9	25	....
4 731.6	40	50	5 570.7	15	15	7 074.8	25	....
4 755.7	8	15	5 610.9	30	1	7 128.9	20	....
4 769.3	6	15	5 620.8	30	1	7 379.7	15	....
4 772.7	6	18	5 669.4	18	....	7 425.5	18	....
4 819.5	12	12	5 723.6	15	1	7 533.9	20	....
4 847.7	10	10	5 780.6	40	....	7 784.1	29	....
4 858.1	15	15	5 798.6	35	1	7 881.9	15	....
4 861.0	18	....	5 802.1	20	....			

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Ti 3771.7	*Co Fe Hg Li Mn	‡Fe 4088.6	‡Au Bi Co Cr Fe
†Fe 4071.7	†Ba Cr Cu Fe	Co 4118.8	
Fe 3820.4		V 4099.8	
Mo 3798.3		§Pb 4168.0	§As Au Ba Ca Co Cr Mg Mn Mo Pb
Ni 3510.3		Pb 4057.8	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

VANADIUM

V

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 004.8	....	50	2 352.3	5	200	2 616.2	4	70
II 2 134.1	30	125	2 357.8	2	60	2 622.7	....	50
II 2 137.3	10	80	2 358.7	....	300	II 2 628.7	4	50
II 2 138.2	8	50	2 367.7	....	80	2 629.7	1	70
II 2 142.0	10	80	2 371.1	....	500	2 630.7	30	150
II 2 143.0	10	50	2 372.2	....	100	2 640.9	2	50
II 2 147.5	2	100	2 373.1	....	200	2 644.4	12	100
II 2 151.8	....	50	2 380.9	6	50	2 645.8	15	100
2 185.4	4	50	2 385.8	....	100	I 2 647.7	50	10
2 201.7	....	50	2 389.7	5	100	2 648.5	2	60
2 202.5	....	50	2 393.6	....	500	2 649.4	2	100
2 209.2	....	50	2 399.7	....	150	I 2 651.9	50	4
2 214.0	....	50	2 400.9	1	50	2 655.7	10	100
2 216.0	2	100	2 404.2	1	90	I 2 661.4	100	80
2 217.4	....	150	2 430.0	....	70	2 663.2	12	100
2 218.4	....	125	2 445.0	2	60	2 670.2	2	70
2 222.7	....	100	2 446.7	1	50	2 672.0	50	300R
I 2 229.7	12	80	2 447.6	....	70	2 673.2	10	60
2 232.9	....	500	2 458.3	1	70	2 677.8	70	300R
2 241.5	....	200	2 465.3	2	100	2 678.6	30	150R
2 285.5	....	100	2 475.5	2	60	2 679.3	70	300R
2 290.5	....	50	2 475.9	....	60	2 682.9	50	200R
2 292.9	....	250	2 479.1	15	150	I 2 683.1	35	150R
2 295.0	5	100	2 479.5	15	150	2 688.0	150	500R
2 297.9	....	100	2 483.1	20	150	I 2 688.7	35	100R
2 309.8	....	125	2 503.0	7	100	2 689.9	50	150R
2 311.3	....	150	2 506.2	10	150	2 690.2	50	200R
2 314.2	....	100	I 2 506.9	50R	35	2 690.8	70	300R
2 318.1	....	250	2 516.1	25	100	2 694.7	2	70
2 319.0	....	150	I 2 519.6	125R	50	I 2 647.0	70	2
2 323.8	....	300	II 2 524.0	10	100	I 2 697.7	100	50R
I 2 324.7	50	....	I 2 526.2	150	150R	2 698.4	30	300
2 325.1	....	100	2 527.9	35	300R	I 2 698.7	70	15
2 328.9	....	100	2 528.5	50	150R	2 700.9	125	500R
2 330.5	8	300	2 528.8	25	150R	2 702.2	80	300R
2 331.8	....	300	I 2 530.2	100	70R	2 705.2	25	50
2 333.6	....	50	2 533.8	5R	60	2 706.2	100	400R
2 334.2	....	250	II 2 534.5	10	80	2 706.7	60	200R
2 335.5	....	250	I 2 546.0	50	10	2 707.9	70	150
2 336.1	2	50	II 2 548.7	10	80	2 710.2	6	60
2 337.1	....	100	I 2 552.7	75R	10	2 711.7	50	150R
2 337.3	....	80	I 2 562.1	50	4	2 713.0	40	80
I 2 340.5	50	3	I 2 574.0	60	50	2 714.2	60	100
2 342.1	4	125	II 2 574.5	9	80	2 715.7	50	300R
2 343.1	....	250	2 583.0	....	50	I 2 722.6	100	40
2 346.3	....	125	2 585.0	2	100	2 726.5	7	80
2 347.2	....	150	2 593.1	....	50	2 728.6	50	400R
2 349.8	3	150	2 595.1	....	70	I 2 731.3	80	50
2 351.5	....	50	2 615.4	....	50	2 739.7	50	80

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

VANADIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 747.5	6	60	II 2 908.8C	70R	400R	I 3 043.1	60	7
2 753.4	50	200R	II 2 910.0	35	150R	I 3 043.6	60	40
2 760.7	25	100	II 2 910.4	35	150R	3 048.2	10	125R
2 765.7	50	200	II 2 911.1	30	200R	3 038.9	10	50
II 2 766.5	40	100	I 2 914.9	60	50R	3 050.7C	1	50
2 768.6	35	150R	II 2 920.0	10	70R	I 3 052.2	50	5
2 771.4	6	50	II 2 920.4	20	125R	II 3 053.4	10	90R
2 772.0	2	80	I 2 923.6	50R	150R	I 3 053.7	90R	....
2 774.3	25	100R	II 2 924.0LC	70R	300R	3 053.9C	10	60R
2 774.7	20	50	II 2 924.6C	60	200R	3 055.9	....	50
2 775.8	12	70	II 2 930.8	30	150R	I 3 056.3C	125R	70R
II 2 777.7	40	100R	2 932.3	12	80	I 3 060.5C	150R	100R
2 778.6	....	60	II 2 934.4	10	50	3 063.2	30	80R
2 781.5	4	125	I 2 938.3	2	60	I 3 066.4C	400R	125R
2 784.3	4	50	II 2 941.4	40	300R	3 070.1	....	50
2 797.0	12	80	II 2 941.5	12	150R	3 072.7	70R	40R
2 797.8	12	70	I 2 942.4	80R	20	I 3 073.8	60	20R
2 798.8	25	80	II 2 944.6	50	300R	3 081.3	5	50
2 799.5	25	100	2 948.1	2	70	I 3 082.1	80R	2
2 810.3	50	50	2 949.2	6	80	3 083.2	2	50
2 817.5	18	50	II 2 950.3	25	100R	I 3 083.5	60	....
2 822.4	4	70	II 2 952.1	35	150R	3 092.7	100R	50R
2 825.9	7	70	2 955.6	1	60	II 3 093.1P*	100R	400R
2 830.4	10	60	I 2 957.5	20	125R	LB$_1$C		
2 836.5	20	80	I 2 962.8	60	60R	3 094.2	20	125R
2 845.2	18	80	2 972.3	2	50	3 100.9	20	100
2 846.6	50	20	2 976.2	6	50	II 3 102.3p†C	70	300R
2 847.6	15	150	I 2 977.5	50	6	3 108.7	3	50
2 849.1	7	50	2 981.2	4	60	3 109.4	1	70
I 2 852.9	60	7	2 982.7	4	50	II 3 110.7pC	70	300R
2 854.3	20	100R	2 983.5	10	60	3 113.6	7	100
I 2 855.2	50	1	2 985.2	1	60	II 3 118.4pC	70	200R
I 2 857.9	50	7	II 2 988.0	10	80	3 120.7	12	80
I 2 860.0	50	10	I 2 990.9	50	5	II 3 121.1	60	200R
2 869.1	25	150R	2 994.5	2	50	3 122.9	12	300R
I 2 870.6	50R	20R	II 2 996.0	5	70	3 125.0C	4	50
2 873.2	4	50	II 3 001.2	20	200R	II 3 125.3p	80	200R
2 877.7	15	100R	II 3 003.5	8	70	II 3 126.2	60	100R
II 2 879.2	50	35	3 005.8	....	50	3 128.3	2	60
II 2 880.0	25	150R	3 006.5	....	50	3 128.7	3	70
II 2 882.5	35	200R	3 008.5	....	50	II 3 130.3B$_2$	50	200R
II 2 884.8	40	200R	3 008.6	3	70	3 132.6	80R	20
2 888.2	20	125R	3 012.0	2	50	II 3 133.3	50	200R
II 2 889.6	40	150R	3 013.1	10	70	3 134.9	30	150R
II 2 891.6L	40	200R	II 3 014.8	10	100	3 136.5	20	200
II 2 892.4	30	150R	II 3 016.8	15	80	3 138.1	....	70
II 2 892.7	30	150R	3 022.6	2	50	3 139.7	15	150
II 2 893.3	50	300R	II 3 025.0	2	60	3 141.5	5	100
II 2 903.1	35	150R	II 3 028.0	2	50	3 142.5	15	100R
II 2 906.5	40	150	II 3 033.8	20	90R	3 143.5	1	50
II 2 907.5	40	150	3 042.3	6	80	3 144.7	1	60

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

VANADIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 146.2	2	70	3 337.8	2	150	3 620.5	10	50
3 146.8	2	50	3 345.9	....	125	3 621.2	15	80
3 148.7	....	50	3 353.8	2	100	3 625.6	4	125
3 151.3	8	150	I 3 356.4	125	60	3 627.7	4	50
3 155.4	5	100	3 361.5	....	200	I 3 629.3	50	2
3 161.3	1	50	I 3 365.6	125	80	3 632.1	....	70
II 3 164.8	10	100	I 3 376.1	80	60	3 635.9	50	25
3 165.9	1	80	I 3 377.6	60	30	I 3 639.0	70	60
3 167.4	5	150R	3 382.5	....	125	I 3 641.1	100	30
3 174.5	1	80	I 3 384.6	60	40	I 3 644.7	80	50
I 3 183.4pC	200R	100R	I 3 400.4	100	8	I 3 649.0	80	50
I 3 184.0P‡C	500R	400R	I 3 402.6	60	25	I 3 656.7	80	20
I 3 185.4p§C	500R	400R	3 404.4	....	50	I 3 661.4	10	150
II 3 187.7	35	100R	3 451.0	....	60	I 3 663.6	150	1
II 3 188.5	35	100R	3 453.1	....	60	3 665.1	100	50
II 3 190.7	50	150R	3 457.2	2	150	I 3 667.7	80	25
I 3 193.9	100	20	3 469.5	2	100	3 669.4	20	300
I 3 198.0	100R	30R	3 470.3	....	70	I 3 671.2	100	70
I 3 202.4	100R	20R	3 477.5	....	100	I 3 672.4	100	40
I 3 207.4	80R	20	II 3 479.8	20	80	I 3 673.4	150	80
II 3 208.4	10	100	I 3 482.2	40	50	I 3 675.7	100	70
I 3 212.4	70	50	II 3 485.9	8	70	3 676.7	300	150
II 3 214.8	20	100	II 3 493.2	15	100	I 3 677.1	25	70
I 3 217.1	30	80	3 497.0	....	150	I 3 680.1	125	50
3 226.9	1	50	II 3 499.8	3	50	I 3 683.1	100	60
3 232.0	8	100	II 3 504.4	60	200	I 3 686.3	100	100
II 3 237.9	30	100	I 3 505.7	50	35	I 3 688.1	200	200R
3 250.8	10	50	3 507.5	....	50	I 3 690.3	200	125
3 251.9	10	50	3 509.0	2	150	I 3 692.2	200R	150R
I 3 254.8	40	80	3 517.3	20	30	I 3 694.6	60	5
II 3 263.3	....	50	II 3 520.0	5	50	I 3 695.3	125	70
II 3 267.7	30	80R	3 521.8	20	80	I 3 695.9	150	100R
II 3 271.1	25	50R	II 3 524.7	10	60	3 700.3	10	100
II 3 276.1	50	200R	II 3 530.8	40	100	I 3 703.6	200R	100R
3 281.1	3	50	II 3 538.2	10	100	I 3 704.7	200R	150R
3 282.5	12	80	I 3 543.5	50	50	I 3 705.0	100	70
II 3 289.4	10	70	II 3 545.2	40	300R	I 3 706.0	50	50
3 290.2	2	70	I 3 553.3	80	30	I 3 708.7	100	60
3 293.2	....	50	3 556.2	40	2	3 711.1	....	80
3 297.5	....	60	II 3 566.2	25	100	I 3 714.0	60	10
I 3 298.1	50	15	I 3 577.9	50	40	3 715.5	70	400R
II 3 298.7	12	80	3 578.6	35	80	II 3 718.2	5	70
3 301.7	....	80	I 3 580.8	50	50	I 3 722.0	70	20
3 304.5	....	125	I 3 583.7	60	30	II 3 727.3	40	200
3 308.5	....	80	II 3 589.8	80	600R	3 728.3	20	150
3 316.9	....	60	II 3 592.0	50	300R	I 3 729.0	80	15
3 317.9	....	80	II 3 593.3	30	300R	3 732.8	70R	500R
3 318.9	....	60	I 3 600.0	15	40	I 3 738.0	50	5
3 321.5	3	150	3 604.4	....	50	I 3 738.8	100	7
I 3 329.9	100	40	I 3 606.7	80	70	I 3 740.2	100	10
3 335.5	1	60	3 618.9	....	100	I 3 741.5	80	8

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

VANADIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
3 745.8	35	600	II 3 916.4	15	40	I 4 875.5	40	20
I 3 748.0	50	4	I 3 922.4	80	40	I 4 881.6	40	30
3 751.2	4	100	I 3 927.9	50	40	I 5 002.3	90	90
I 3 751.8	50	2	I 3 930.0	50	20	I 5 014.6	125	125
I 3 755.7	70	3	I 3 934.0	100	30	5 064.1	50	50
I 3 759.3	50	2	I 3 937.5	50	20	I 5 128.5	75	75
I 3 763.1	80	6	I 3 943.7	50	18	I 5 138.4	50	50
II 3 771.0	30	60	II 3 952.0	35	50	I 5 139.5	50	50
I 3 776.2	50	2	II 3 973.6	25	40	I 5 148.7	60	60
I 3 778.7	60	4	I 3 979.1	50	8	5 176.8	60	50
I 3 787.5	30	1	I 3 988.8	70	35	I 5 193.0	100	75
I 3 795.0	50	50	I 3 990.6	125	40	I 5 240.9	50	50
I 3 799.9	60	50	I 3 992.8	60	20	I 5 353.4	50	50
I 3 803.5	50	40	I 3 998.7	100	25	I 5 393.2	100	....
I 3 807.5	80	50	II 4 002.9	6	80	I 5 401.9	100	100
I 3 808.5	50	30	II 4 035.6	40	80	I 5 415.5	75	75
I 3 809.6	70	40	4 053.6	....	70	I 5 434.2	50	50
I 3 813.5	50	....	4 065.1	2	100	I 5 507.7	60	60
3 815.4	1	150	I 4 067.7	50	15	I 5 592.4	50	50
I 3 820.0	60	35	I 4 090.6	60	25	I 5 604.9	60	20
I 3 821.5	50	30	I 4 111.8‖	100R	100R	I 5 624.6	100	....
I 3 822.0	70	40	I 4 134.5	40R	15	I 5 626.0	150	....
I 3 835.6	50	12	I 4 268.6	40	20	I 5 627.6	200	80
I 3 839.0	60	10	I 4 330.0	40	30	I 5 646.1	150	150
I 3 843.5	50	15	I 4 332.8	60	40	I 5 657.4	150	60
I 3 844.4	100	50	I 4 341.0	60	30	I 5 668.4	75	50
I 3 847.3	100	70	I 4 342.8	50	30	I 5 670.9	150	70
I 3 849.3	60	25	I 4 379.2¶C	200R	200R	5 683.2	50	2
I 3 851.2	50	15	I 4 384.7**C	125R	125R	I 5 698.5	300	300
I 3 855.4	50R	50R	I 4 390.0††	80R	60R	I 5 703.6	200	60
I 3 855.8	200	200	I 4 395.2	60R	40R	I 5 707.0	200	....
I 3 858.7	50	15	I 4 400.6	60	40	I 5 716.2	60	30
I 3 862.2	80	20	I 4 406.6	40	30	I 5 727.0	150	150
I 3 864.9	100R	50R	I 4 408.5‡‡C	30	20R	I 5 727.7	75	....
II 3 866.7	5	50	I 4 421.6	30	20	I 5 731.2	250	100
I 3 867.6	70	35	I 4 441.7	40	30	I 5 737.1	100	100
I 3 871.1	60	35	I 4 488.9	60	30	I 5 743.5	60	20
I 3 875.1	70R	50	I 4 545.4	40	30	I 5 750.6	50	....
II 3 878.7	35	100	4 564.6	....	150	I 5 772.4	50	25
I 3 876.1	50	30	I 4 571.8	30	25	I 5 776.7	50	25
I 3 879.7	50	5	I 4 577.2	40	30	I 5 784.4	50	30
II 3 884.8	4	70	I 4 580.4	30	25	I 5 786.2	75	....
I 3 890.2	100	30	I 4 586.4	40	30	I 5 807.1	75	40
I 3 892.9	60	35	I 4 594.1	30	25	I 5 817.1	50	....
I 3 900.2	50	2	4 600.2	1	60	I 5 817.5	100	....
I 3 901.2	50	3	I 4 670.5	60R	40R	I 5 830.7	100	80
I 3 906.7	50	20	I 4 786.5	30	25	I 5 846.3	100	100
3 908 3	50	2	I 4 796.9	30	25	I 5 924.6	250	....
I 3 909.9	50	30	I 4 807.5	40	30	I 5 978.9	100	....
I 3 912.2	50	20	I 4 851.5	40	30	I 5 980.8	50	....
II 3 914.3	25	70	I 4 864.7	30	25	I 6 039.7	100	10

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

VANADIUM (*Continued*)

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spar
I 6 058.1	60	....	I 6 216.4	60	10	I 6 274.7	50	8
I 6 077.4	300	2	I 6 224.5	50	5	I 6 285.2	50	10
I 6 081.4	100	10	I 6 230.7	70	10	I 6 292.8	50	10
I 6 090.2	60	15	I 6 243.1	35	4	I 6 296.5	35	30
I 6 119.5	30	20	I 6 251.8	70	8	I 6 753.0	40	....
I 6 199.2	100	8	I 6 268.1	30	5	I 7 338.9	50	....
I 6 213.9	50	3						

Control lines:	Interfering lines:
*Al 3961.5	*Al Au Bi Fe Mg
Fe 3222.1	
Mg 3096.9	
†Fe 3057.5	†Co K Ni W
Ni 3050.5	
Ti 3106.2	
‡Ca 3706.0	‡Ag Ba Ni Ti W Ce Th V
Cr 3120.4	
Ti 3199.9	
§Ti 3199.9	§Mo P Ce Co U Rh Th Fe

Control lines:	Interfering lines:
‖Co 4092.4	‖Ba Co Cr Fe Mn Mo
¶Fe 4045.8	¶Al Bi Cd Co Cr Cu Rh Z Ag Ta W Cb Ir
Mo 4277.3	
**Cr 4371.3	**Al Bi Co Cr Fe Mo
Fe 4045.8	
Mo 4277.3	
††Pb 4245.2	††Al Bi Co Cr Mn Mo
W 4372.6	
‡‡Fe 4383.5	‡‡Al Ba Be Co Cr Cs Fe
Mo 4381.7	

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

YTTERBIUM

Yb

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
2 098.4	....	50	3 192.9	12	80	4 820.2	15	60
2 102.7	20	200	3 275.8	12	100	4 935.5	200	10
2 116.7	50	250	3 289.4	500R	1000R	4 937.2	6	80
2 119.6	....	100	3 289.9	1000	....	5 009.5	20	50
2 126.7	40	200	3 305.7	30	125	5 074.3	200	5
2 154.2	....	80	3 333.1	20	60	5 076.8	50	1
2 161.6	100	250	3 337.2	25	30	5 104.4	1	50
2 185.7	60	100	3 362.4	15	....	5 244.1	50	5
2 265.7	3	50	3 363.6	10	....	5 257.5	15	100
2 305.3	8	100	3 366.0	4	30	5 277.1	200	6
2 314.4	4	80	3 375.5	30	100	5 279.6	15	100
2 464.5	5	2	3 428.5	25	80	5 335.2	150	400
2 512.1	10	50	3 438.7	4	80	5 345.7	20	100
2 579.6	5	200	3 438.8	20	100	5 351.3	50	3
2 581.1	20	100	3 446.9	10	50	5 353.0	100	250
2 599.2	2	50	3 454.1	40	250	5 358.6	15	100
2 621.1	2	100	3 458.3	12	100	5 432.7	5	100
2 638.1	1	60	3 464.4	200R	50R	5 449.3	20	100
2 642.6	3	80	3 476.3	30	10	5 478.5	10	50
2 651.7	2	60	3 478.8	40	300	5 481.9	50	2
2 652.2	2	60	3 495.9	20R	....	5 539.1	200	5
2 653.8	50	200	3 507.8	12	60	5 556.5	1500	50
2 665.0	10	60	3 520.3	10	70	5 588.5	30	100
2 666.1	5	150	3 560.3	20	50	5 652.0	50	80
2 667.0	5	150	3 560.7	8	100	5 720.0	300	8
2 672.7	20	80	3 600.7	8	100	5 730.0	4	60
2 750.5	20	150	3 606.5	15	60	5 819.4	7	100
2 818.8	....	80	3 611.3	12	50	5 834.0	60	1
2 851.1	10	50	3 619.8	30	100	5 837.2	50	150
2 891.4	50	100	3 669.7	50	80	5 898.8	3	50
2 914.2	10	60	3 675.1	50	200	5 946.0	4	100
2 919.4	15	90	3 690.6	10	50	5 991.5	50	150
2 945.9	10	60	3 694.2	500R	1000R	6 152.6	60	80
2 970.5	150	150	3 770.1	12	15	6 247.0	40	60
2 984.0	10	70	3 900.9	50	10	6 260.8	4	50
2 994.8	10	80	3 904.8	12	150	6 274.8	100	150
3 002.6	15	150	3 988.0p	1000R	500R	6 355.4	2	50
3 005.8	10	100	3 991.0	60	20	6 400.4	200	4
3 009.4	2	20	4 089.7	10	4	6 418.0	125	3
3 010.6	2	10	4 135.1	15	50	6 463.2	10	100
3 017.6	3	40	4 180.8	10	100	6 474.7	5	50
3 029.6	1	40	4 218.6	3	50	6 489.1	800	40
3 031.1	100	30	4 439.2	45	10	6 492.7	3	50
3 042.7	5	50	4 515.1	45	100	6 643.5	50	....
3 065.0	4	30	4 553.6	20	60	6 667.9	1000	20
3 107.9	10	60	4 576.2	90	10	6 727.6	30	60
3 117.8	7	30	4 582.4	80	6	6 768.7	80	2
3 126.1	1	25	4 598.4	25	70	6 799.6	1000	50
3 140.9	8	30	4 726.1	45	200	7 527.6	80	....
3 153.9	3	30	4 781.9	50	5	7 699.5	2000	....
3 169.1	2	20	4 786.6	50	200			

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

YTTRIUM

Y

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 422.2	20	30	I 4 077.4	50	40	II 5 205.7	50	80
2 946.0	2	100	I 4 083.7	50	10	I 5 466.5	150	20
II 3 055.2	8	50	I 4 102.4	150	30	II 5 497.4	20	40
II 3 086.9	12	50	I 4 128.3	150	30	I 5 503.5	10	2
II 3 129.9	8	50	I 4 142.8	100	25	II 5 509.9	30	40
II 3 173.1	20	70	I 4 167.5	50	10	I 5 521.6	5	....
II 3 195.6	30	50	I 4 174.1	100	8	II 5 521.7	4	40
II 3 200.3	30	40	II 4 177.6	50	50	I 5 527.5	100	15
II 3 203.3	30	50	I 4 235.9	60	30	II 5 544.6	10	80
II 3 216.7	40	70	I 4 302.3	30	8	I 5 581.9	100	10
II 3 242.3‖C	60	100	II 4 309.6	50	50	I 5 630.1	80	....
II 3 327.9	60	60	I 4 348.8	100	....	II 5 662.9	20	400
II 3 362.0	12	25	II 4 358.7	60	50	I 5 706.7	15	1
II 3 496.1	20	35	II 4 374.9	150	150	II 5 728.9	3	25
II 3 549.0	12	50	II 4 375.0§	150	150	I 6 138.4	7	4
II 3 584.5	20	15	II 4 398.0	150	100	I 6 191.7	8	5
I 3 592.9	80	25	I 4 422.6	60	60	I 6 435.0	150	50
II 3 600.7*	100	300	I 4 506.0	50	50	I 6 538.6	50	10
II 3 601.9	18	60	I 4 527.2	40	50	I 6 687.6	50	10
II 3 611.0	40	60	I 4 643.7F	50	100	I 6 700.7	12	8
II 3 628.7	40	50	I 4 674.8F	80	100	I 6 736.0	12	4
II 3 633.1	50	100	II 4 782.3	60	100	I 6 793.7	70	15
II 3 664.6	100	100	I 4 728.5	60	4	II 6 795.4	12	20
II 3 668.5	7	20	I 4 761.0	50	25	I 6 845.2	15	5
II 3 710.3†C	80	150	II 4 823.3	15	10	I 6 887.2	8	12
II 3 747.6	12	15	II 4 854.9	100	150	I 6 950.3	20	10
II 3 774.3‡	12	100	I 4 859.8F	50	5	II 6 951.7	5	8
II 3 788.7	30	30	II 4 883.7	20	300	I 6 979.9	15	6
II 3 818.3	30	50	II 4 900.1	20	300	7 191.6	20	5
II 3 832.9	30	80	II 4 982.1	8	50	II 7 264.2	15	20
II 3 950.4	60	100	II 5 087.4	50	100	I 7 346.5	40	4
II 3 982.6	60	100	II 5 123.2	10	30	II 7 450.3	15	10
I 4 047.6	50	10	II 5 200.4	60	150	II 7 881.9	25	10

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Co 3594.9	*Al Co Cu Mo	V 3750.9	
Cr 3595.5		§Cr 4337.6	§Al Cd Co Cr Cu Fe
†Ca 3736.9	†Co Cr Fe Mg Mo Na Sb Cb Ti Ce	Mo 4377.8	
Fe 3767.2		Fe 4337.1	
‡Ti 3786.1	‡Co Mg Mn Ti		
	‖Fe Ni Ta Pd Ce W U Ti		

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

Principal Lines by Elements

ZINC

Zn

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spark
II 2 025.5p	200	200	I 2 756.5	200	100	I 4 298.3	25	25
II 2 061.9pS$_1$	100	100	I 2 770.9	300	25	I 4 629.8	35	....
II 2 099.9	....	5	I 2 771.0	300	150	I 4 680.1S$_{12}$C	300	200
I 2 138.6pS$_2$N$_1$§	800R	500	I 2 781.2	25	5	I 4 722.2‡C	400	300
II 2 210.9	....	50	I 2 800.9	400	300	I 4 810.5N$_6$C	400	300
2 312.7	10	....	I 2 801.1	100	20	II 4 911.7	15	25
2 393.8	15	....	II 2 801.8	....	25	II 4 924.0	15	30
I 2 449.7	10	....	I 3 018.4	125	40	I 5 182.0	200	2
I 2 463.5	20	2	I 3 035.8S$_5$	200	100	I 5 308.6	8	....
I 2 469.4	12R	....	I 3 072.1	200	125	I 5 310.2	7	....
I 2 479.7	30	....	I 3 075.9S$_6$C	150	50	I 5 311.0	7	....
I 2 491.5	100	50	I 3 282.3pS$_7$C	500R	300	I 5 777.1	10	15
I 2 493.3	25	....	I 3 302.6p*S$_8$N$_3$	800	300	II 5 894.4	3	30
II 2 502.0S$_3$	20	400	3 302.9S$_5$N$_4$C	700R	300R	II 6 021.3	3	15
I 2 515.8	150	20	I 3 345.0p†			II 6 102.5	6	20
I 2 530.1	10	....	LS$_{10}$N$_5$	800	300	II 6 111.6	8	10
I 2 542.3	40	....	I 3 345.6A$_1$S$_{11}$C	500	100	II 6 214.6	3	12
II 2 558.0S$_4$N$_2$	10	300	I 3 345.9	150	50	I 6 237.9	8	....
II 2 568.1	50	10	3 624.1	10	3	I 6 239.2	8	....
I 2 569.9	100	5	3 639.5	20	[5]	I 6 362.3	1000	500
I 2 582.4	100	....	II 3 683.5	20	[15]	I 6 479.2	10	....
I 2 582.5	300	40	3 740.0	20	....	II 6 483.0	4	15
I 2 600.9	10	....	II 3 793.9	10	....	II 6 483.3	....	30
I 2 608.6	200	50	II 3 806.4	3	15	I 6 928.3	15	....
I 2 608.6	300	100	II 3 840.3	3	50	I 6 938.5	8	....
I 2 670.5	200	4	I 3 883.3	50	2	II 7 478.8	....	50
I 2 684.2	300	6	II 4 057.7	80	....	II 7 588.5	....	50
I 2 712.5	300	8	I 4 292.9	25	25	I 7 799.4	10	....

Control lines:
*Fe 3407.5
Pt 3042.6

Interfering lines:
*Cr Na Pt Sr

Control lines:
†Mo 3358.1
Ti 3239.0

Interfering lines:
†Ca Hg Mn Mo Ce Cr Zr

Control lines:
S$_1$Pb 2052.0
S$_2$Pb 2175.6
S$_3$Pb 2388.8
S$_4$Pb 2628.3
S$_5$Pb 2980.3
2926.8
S$_6$Pb 3119.1
S$_7$Pb 3220.5
S$_8$Pb 3220.5
3362.4
2657.2
A$_1$Mg 2916

‡Ti Bi Sr V
§Co Ni Ir As Cu W

Control lines:
S$_9$Pb 3220.5
3262.4
2657.2
S$_{10}$Pb 3220.5
3262.4
S$_{11}$Pb 3220.5
S$_{12}$Pb 5043.1
N$_1$Pb 2190.0
2187.9
2176.5

Control lines:
2159.6
2111.8
N$_2$Pb 2562.4
N$_3$Sn 3352.3
2175.0
N$_4$Pb 3119.2
N$_5$Sn 3330.6
Pb 3220.5
N$_6$Pb 5005.5

For explanation of control and interfering line symbols see page 445.

TABLE VI (*Continued*)

PRINCIPAL LINES BY ELEMENTS

ZIRCONIUM

Zr

Wavelength	Arc	Spark	Wavelength	Arc	Spark	Wavelength	Arc	Spar
2 285.2	100	....	II 3 438.2p†C	250	200	II 4 156.2	25	15
2 291.1	80	15	I 3 447.4	150	3	II 4 161.2	40	30
II 2 294.0	50	10	II 3 463.0	18	40	I 4 166.4	50	4
2 303.1	100	....	II 3 479.4	60	80	I 4 201.5	50	3
2 331.6	....	100	II 3 481.1	50	80	I 4 227.8	150	8
II 2 449.8	50	20	II 3 496.2‡C	100	100	I 4 239.3	100	5
I 2 539.7	50	....	II 3 505.5	30	30	I 4 240.4	100	1
II 2 542.1	100	50	II 3 505.7	40	30	I 4 241.2	100	2
I 2 550.5	15	....	I 3 519.6	100	10	I 4 241.7	100	2
II 2 550.7	100	50	II 3 542.6	12	30	I 4 256.0	60	....
II 2 567.6	100	100	I 3 547.7	200	12	II 4 282.2	30	4
II 2 568.9	100	200	II 3 556.6	15	50	I 4 302.9	100	1
II 2 571.4	300R	400R	II 3 572.5	60	80	I 4 341.1	50	5
II 2 578.6	80	100	I 3 575.8	100	5	I 4 347.9	40	5
II 2 678.6	80	100	II 3 576.9	15	25	I 4 575.5	50	....
II 2 700.1	50	50	I 3 601.2	400	15	I 4 633.9	35	....
II 2 722.6	50	50	II 3 611.9	15	40	I 4 678.8p	125	....
II 2 734.8	40	40	II 3 614.8	40	80	I 4 688.4	50	....
II 2 726.5	50	50	II 3 636.4	200	30	I 4 710.1p	60	....
II 2 752.2	40	40	I 3 663.7	100	10	I 4 739.5P	100	....
II 2 798.3	100	....	II 3 674.7	100	40	I 4 772.3P	100	....
I 2 814.9	70	1	II 3 698.2	50	80	I 4 815.6	40	....
I 2 837.2	100	....	II 3 709.3	50	30	I 5 046.6	25	....
II 2 844.6	50	50	II 3 751.6	25	40	I 5 155.4	15	....
I 2 848.5	100	....	3 825.3	40	60	I 5 385.1	15	....
I 2 876.0	70	1	I 3 835.9	25	5	I 5 664.5	50	....
I 2 885.4	50	3	I 3 864.3	50	20	I 5 680.9	50	....
II 2 968.9	15	30	I 3 890.3	150	6	I 5 797.7	50	....
I 2 985.4	50	3	I 3 891.4	100	5	I 5 879.8	60	....
I 3 011.7	100	4	I 3 900.5	100	....	I 6 121.9	60	....
II 3 020.5	50	30	II 3 914.3	70	8	I 6 127.4	500	....
I 3 029.5	60	5	II 3 915.9	25	15	I 6 134.4	70R	....
II 3 182.9	12	18	I 3 921.8	100	4	I 6 143.2	300	....
II 3 273.0	50	80	II 3 958.2	500	150	I 6 299.7	50	....
II 3 279.3	50	50	3 961.6	500	8	I 6 313.0	200	....
II 3 284.7	25	30	I 3 968.3	100	4	I 6 470.2	40	....
II 3 306.3	80	80	I 3 975.3	50	1	I 6 489.6	50	....
II 3 326.8	100	100	II 3 991.1	100	60	I 6 762.4	50	....
II 3 356.1	50	40	II 3 998.9	30	30	I 6 769.2	50	....
II 3 357.3	50	40	I 4 027.2	100	4	I 6 953.8	80	....
II 3 387.9	100	100	II 4 048.7	30	30	I 6 990.8	50	....
II 3 388.3	50	40	I 4 055.0	100	5	I 7 097.7	100	....
II 3 392.0P*C	300	400	I 4 064.2	100	6	I 7 102.9	80	....
II 3 399.3	100	40	I 4 072.7	100	3	I 7 103.7	50	....
II 3 410.2	50	50	I 4 081.2	150	7	I 7 169.1	150	....
II 3 430.5	50	50	II 4 149.2	100	100			

Control lines:	Interfering lines:	Control lines:	Interfering lines:
*Co 3409.2	*Bi Fe Hg Mo Ni Th Cu Ce W Cr	Ni 3446.3	
Ni 3380.6		‡Ba 4130.6	‡Cd Co Ga Mn Mo Ni Ca Y Cb Ti
Ti 3387.8		Ba 4166.0	
†Fe 3581.2	†Co Fe Mo Ni V Ce	Co 3409.2	
Mn 2933.1		Fe 3558.5	

For explanation of control and interfering line symbols see page 445.

TABLE VII

SPARK SPECTRUM OF AIR

(*A55, A48, A35*)

Wavelength	Intensity	Element	Wavelength	Intensity	Element	Wavelength	Intensity	Element
2 287.9	1	N	3 577.2	1	—	4 093.00	2	O
2 318.5	1	O	3 589.0	1	—	4 097.2	3	N
2 382.1	2	—	3 594.6	1	—	4 103.3	2	N
2 395.62	1	—	3 609.8	1	—	4 105.00	3	O
2 399.4	1	—	3 639.6	3	—	4 110.84	2	O
2 404.9	2	—	3 702.9	1	—	4 112.09	1	O
2 406.9	1	—	3 707.3	1	O	4 114.0	0	O
2 433.6	1	O	3 709.2	1	O	4 119.3	4	O
2 445.5	1	O	3 712.7	2	O	4 120.5	2	O
2 507.2	2	—	3 727.34	4	O	4 121.5	2	O
2 514.5	1	—	3 729.3	1	N	4 124.1	2	O
2 599.5	2	—	3 749.51	5	O	4 129.5	1	O
2 739.8	1	—	3 754.5	1	O	4 132.88	2	O
2 746.7	1	—	3 759.8	1	O	4 133.70	2	N
2 749.0	1	—	3 770.9	1	N	4 142.2	1	O
2 755.9	2	—	3 804.0	1	O	4 143.7	1	O
2 795.5	1	—	3 830.7	1	N	4 145.90	3	N
2 858.3	1	—	3 839.1	2	N	4 153.5	3	O
2 927.5	1	—	3 842.8	1	N	4 169.36	1	O
3 007.0	1	O	3 845.1	0	N	4 176.2	2	N
3 047.0	1	—	3 848.04	1	O	4 185.5	4	O
3 059.15	2	—	3 850.6	1	N	4 189.8	6	O
3 130.1	1	—	3 851.2	1	O	4 199.3	0	N
3 135.3	1	O	3 856.7	1	N	4 206.7	2	N
3 139.3	2	O	3 864.6	1	O	4 211.1	1	N
3 158.7	1	—	3 882.3	2	O	4 223.3	1	N
3 265.2	1	O	3 893.3	1	N	4 228.0	2	N
3 288.9	1	—	3 907.6	1	O	4 236.8	3	N
3 301.9	1	—	3 909.1	1	N	4 241.75	2	N
3 312.5	1	O	3 912.1	3	O	4 253.7	2	O
3 318.8	1	—	3 919.10	6	N	4 266.4	2	N
3 320.7	2	O	3 940.2	1	N	4 275.9	1	N
3 325.0	1	O	3 945.1	1	O	4 303.7	1	O
3 329.5	2	N	3 947.45	1	O	4 317.11	3	O
3 331.8	2	N	3 954.4	1	O	4 319.62	3	O
3 344.8	1	—	3 955.9	4	N	4 325.7	1	O
3 354.08	1	O	3 973.30	4	O	4 327.5	1	O
3 365.8	1	N	3 982.76	2	O	4 328.5	1	O
3 367.3	1	N	3 995.1	10	N	4 331.04	1	N
3 370.9	1	N	4 014.0	1	O	4 331.9	1	O
3 374.0	2	N	4 025.7	1	N	4 336.8	2	O
3 377.2	2	O	4 034.9	2	N	4 345.54	3	O
3 390.3	2	O	4 041.3	3	N	4 347.44	2	O
3 408.3	2	O	4 057.8	1	N	4 348.0	2	N
3 437.32	3	N	4 063.2	1	N	4 349.40	4	O
3 450.9	1	—	4 069.90	8	O	4 351.3	2	O
3 471.2	2	—	4 072.25	8	O	4 361.6	0	N
3 491.9	2	—	4 075.93	8	O	4 366.87	3	O
3 514.8	1	—	4 078.9	2	O	4 369.2	1	O
3 560.6	1	—	4 085.20	2	O	4 371.4	1	N
3 570.3	1	—	4 089.1	1	O	4 379.6	1	N

(Intensities according to Kayser, "Handbuch der Spektroscopie.")

TABLE VII (*Continued*)

SPARK SPECTRUM OF AIR

Wavelength	Intensity	Element	Wavelength	Intensity	Element	Wavelength	Intensity	Element
4 396.0	1	O	4 803.3	5	N	5 480.1	1	N
4 401.2	1	N	4 805.9	1	N	5 495.7	2	N
4 414.9	6	O	4 810.3	2	N	5 526.2	2	N
4 417.0	5	O	4 856.8	1	O	5 530.2	3	N
4 425.9	1	N	4 860.3	1	N	5 535.2	5	N
4 430.1	1	N	4 871.6	0	O	5 543.4	3	N
4 432.4	2	N	4 879.7	1	N	5 552.0	2	N
4 434.0	0	N	4 890.9	0	O	5 566.0	0	N
4 443.3	1	O	4 895.3	1	N	5 592.3	0	O
4 447.04	6	N	4 906.8	1	O	5 645.6	1	N
4 452.4	2	O	4 924.6	2	O	5 666.6	5	N
4 460.1	1	N	4 934.8	1	N	5 675.9	3	N
4 465.4	2	O	4 941.0	1	N	5 679.5	10	N
4 467.8	2	O	4 942.5	1	N	5 686.2	3	N
4 469.4	1	O	4 943.0	1	O	5 710.7	2	N
4 477.7	1	N	4 955.0	1	O	5 730.6	2	N
4 507.62	2	N	4 964.7	0	N	5 747.5	1	N
4 514.8	2	N	4 987.4	1	N	5 767.4	2	N
4 529.9	2	N	4 991.3	1	N	5 927.8	4	N
4 544.8	1	N	4 994.4	3	N	5 931.8	7	N
4 552.5	2	N	5 001.4	6	N	5 940.5	1	N
4 590.93	3	O	5 005.2	6	N	5 941.6	10	N
4 596.12	3	O	5 007.4	3	N	5 952.4	4	N
4 601.48	4	N	5 010.6	2	N	6 158.1	0	O
4 607.14	4	N	5 016.4	2	N	6 171.0	2	O
4 609.4	1	N	5 022.9	1	N	6 284.3	1	N
4 613.84	3	N	5 025.7	2	N	6 341.5	0	N
4 621.39	4	N	5 045.1	2	N	6 358.1	0	N
4 630.53	10	N	5 061.8	0	N	6 379.3	2	N
4 634.0	1	N	5 073.5	0	N	6 456.0	0	O
4 638.8	2	O	5 143.6	0	O	6 482.0	5	N
4 640.5	1	N	5 160.1	0	O	6 563.2	3	H
4 641.8	3	O	5 172.0	1	N	6 610.4	6	N
4 643.1	4	N	5 173.4	1	N	6 654.8	2	—
4 649.1	4	O	5 175.9	2	N	6 887.6	1	—
4 650.8	2	O	5 179.4	1	N	6 965.9	1	A
4 654.5	1	N	5 183.2	0	O	7 067.6	0	A
4 661.6	5	O	5 185.1	0	N	7 157.4	9	O
4 674.9	1	N	5 190.6	1	N	7 384.5	1	A
4 676.2	3	O	5 206.5	1	O	7 424.0	8	N
4 699.2	3	O	5 281.7	0	N	7 442.7	10	N
4 703.1	0	O	5 320.5	1	N	7 468.7	10	N
4 705.1	1	N	5 325.1	0	O	7 479.0	0	O
4 705.4	3	O	5 328.6	0	N	7 505.8	0	A
4 709.9	2	O	5 328.7	1	N	7 515.2	0	A
4 718.4	2	N	5 341.2	1	N	7 635.7	1	A
4 735.7	1	N	5 351.2	0	N	7 772.1	10	O
4 751.2	1	O	5 356.4	0	N	7 774.3	7	O
7 764.6	1	N	5 411.5	1	N	7 775.6	6	O
4 774.2	1	N	5 452.1	1	N	7 947.8	4	O
4 779.8	2	N	5 454.7	1	N	7 951.1	3	O
4 788.2	4	N	5 462.8	1	N	7 952.3	2	O

(Intensities according to Kayser, "Handbuch der Spektroscopie.")

TABLE VIII

Principal Lines by Elements (*Discharge Spectrum*)

+ *indicates secondary standards* (*see Neon*)

(*A52, A48, A36*)

ARGON

A

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
II 2 152.6	60	I 3 649.8	800	4 348.1	500
II 2 159.0	60	I 3 659.5	100	I 4 363.8	80
2 162.7	60	I 3 670.6	300	4 371.4	80
2 164.2	100	I 3 675.2	300	4 379.7	80
II 2 171.4	60	I 3 690.9	300	I 4 424.0	80
2 213.0	60	3 729.3	200	4 426.0	300
2 218.9	60	I 3 743.8	100	4 430.2	100
2 222.9	60	I 3 770.4	400	4 431.0	80
2 227.7	60	3 780.8	50	II 4 481.8	80
II 2 238.2	60	I 3 781.4	300	I 4 510.7	1000
2 280.6	60	I 3 834.7	800	I 4 522.3	800
2 287.8	60	3 850.6	400	4 545.1	200
2 313.7	60	I 3 894.7	300	4 579.4	80
2 316.3	100	I 3 899.9	100	I 4 589.3	80
2 331.5	60	3 928.6	125	II 4 589.9	150
2 337.8	60	3 944.3	50	I 4 596.1	1000
2 351.6	60	I 3 947.5	1000	II 4 609.6	300
II 2 942.9	100	I 3 949.0	2000	I 4 628.4	1000
3 169.7	50	3 968.4	200	I 4 642.1	80
I 3 173.0	150	4 013.9	200	4 657.9	150
I 3 200.4	100	II 4 042.9	80	I 4 702.3	1200
I 3 234.5	100	I 4 044.4	1200	4 726.9	200
I 3 257.6	100	I 4 046.0	150	4 735.9	400
I 3 319.3	300	I 4 054.5	80	I 4 746.8	80
I 3 325.5	100	II 4 072.0	150	I 4 752.9	150
I 3 373.5	300	4 103.9	200	4 764.9	150
I 3 392.8	100	II 4 131.7	80	I 4 768.7	150
I 3 393.8	250	4 154.5	80	4 806.1	500
I 3 461.1	300	I 4 158.6	1200	I 4 836.7	150
3 491.5	50	I 4 164.2	1000	4 847.9	80
3 514.4	125	I 4 181.9	1000	I 4 876.3	200
3 545.6	300	I 4 190.7	600	4 879.9	300
II 3 545.8	125	I 4 191.0	1200	I 4 887.9	200
I 3 556.0	100	I 4 198.3	1200	I 4 894.7	150
I 3 563.3	100	I 4 200.7	1200	I 4 921.0	80
I 3 564.3	100	I 4 251.2	800	I 4 956.8	100
I 3 567.7	300	I 4 259.4	1200	I 4 989.9	80
I 3 572.3	300	I 4 266.3	1200	5 009.4	200
3 576.6	300	4 266.5	200	II 5 017.2	60
3 582.4	50	I 4 272.2	1200	I 5 032.0	60
3 588.4	300	II 4 277.6	80	I 5 048.8	500
I 3 606.5	1000	I 4 300.1	1200	I 5 054.2	300
I 3 632.7	300	4 332.1	80	I 5 060.1	500
I 3 634.5	300	I 4 333.6	1000	5 062.1	200
II 3 634.8	240	I 4 335.3	800	I 5 073.1	200
I 3 643.1	100	I 4 345.2	1000	5 087.1	60

TABLE VIII (*Continued*)

Principal Lines by Elements (*Discharge Spectrum*)

ARGON (*Continued*)

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
I 5 118.2	60	I 5 597.5	500	I 6 384.7	100
I 5 127.8	60	I 5 601.1	60	I 6 416.3	100
5 145.4	200	I 5 606.7	500	II 6 643.8	100
I 5 151.4	200	I 5 618.0	60	I 6 660.6	100
I 5 162.3	500	I 5 620.9	60	I 6 664.0	100
I 5 187.7	800	I 5 623.8	60	I 6 698.9	100
I 5 192.7	60	I 5 635.5	60	I 6 719.2	100
I 5 210.5	200	I 5 639.1	100	I 6 752.8	200
I 5 214.8	200	I 5 641.3	60	I 6 756.1	100
I 5 216.3	60	I 5 648.7	200	I 6 766.6	100
I 5 221.3	500	I 5 650.7	1500	I 6 871.3	150
I 5 241.1	60	I 5 659.1	500	I 6 888.2	400
I 5 252.8	300	I 5 681.9	500	I 6 937.7	100
I 5 254.5	60	I 5 689.6	200	I 6 965.4	400
I 5 286.1	60	I 5 689.9	200	I 7 030.3	100
I 5 317.7	60	I 5 700.9	60	I 7 067.2	400
I 5 347.4	200	I 5 739.5	500	I 7 107.5	200
I 5 373.5	500	II 5 772.1	100	I 7 207.0	100
I 5 394.0	200	I 5 834.3	60	I 7 272.9	100
I 5 410.5	500	I 5 860.3	60	I 7 311.7	100
I 5 421.3	500	I 5 882.6	100	I 7 353.3	100
I 5 440.0	500	I 5 888.6	300	I 7 372.1	100
I 5 442.2	500	I 5 912.1	500	I 7 384.0	400
I 5 443.2	100	I 5 928.8	200	II 7 440.5	90
I 5 451.7	500	I 6 032.1	60	I 7 503.9	700
I 5 457.4	200	I 6 043.2	100	II 7 505.1	100
I 5 473.4	500	I 6 059.4	100	I 7 514.7	200
I 5 490.1	60	I 6 098.8	60	II 7 589.3	250
I 5 495.9	1000	I 6 105.6	60	II 7 618.0	80
I 5 506.1	500	II 6 114.9	100	I 7 628.9	50
I 5 524.9	300	I 6 145.4	100	I 7 635.1	500
I 5 534.5	60	I 6 155.2	60	I 7 670.0	50
I 5 558.7	500	I 6 170.2	100	I 7 723.8	200
I 5 559.6	200	I 6 173.1	100	I 7 724.2	200
I 5 572.5	500	I 6 212.5	100	I 7 891.1	100
I 5 581.8	60	I 6 215.9	60	I 7 948.2	400
I 5 588.7	500				

TABLE VIII (*Continued*)

Principal Lines by Elements (*Discharge Spectrum*)

BROMINE

Br

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
2 389.7	70	4 767.1	200	5 536.3	50
2 521.7	50	4 776.4	200	5 589.9	250
II 3 914.3	150	I 4 780.3	125	5 830.7	100
I 4 175.8	50	II 4 785.5	400	I 5 833.4	80
4 223.9	80	II 4 816.7	300	I 5 852.1	150
4 291.4	150	II 4 848.8	150	I 5 940.5	60
4 365.6	200	4 928.8	150	I 6 122.1	50
I 4 441.7	80	4 930.7	50	I 6 148.6	200
I 4 472.6	125	I 4 979.8	125	I 6 350.7	200
I 4 477.8	200	5 038.8	60	I 6 544.6	100
I 4 513.4	100	5 054.7	200	I 6 559.8	150
I 4 525.6	125	II 5 182.4	100	I 6 582.2	100
I 4 529.8	80	II 5 238.2	100	I 6 631.6	200
4 542.9	250	5 332.0	100	I 6 682.3	90
I 4 575.8	100	5 335.1	70	I 6 692.2	70
II 4 614.6	100	I 5 345.4	80	I 6 790.1	70
4 622.8	200	I 5 395.5	150	I 7 005.2	200
4 678.7	200	I 5 466.2	150	7 260.5	50
II 4 704.9	250	5 488.8	70	I 7 348.6	500
4 719.8	80	5 495.1	150	I 7 425.9	100
4 742.7	200	5 506.8	300	I 7 513.0	50
I 4 752.3	100				

CHLORINE

Cl

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
II 2 434.1	50	II 3 861.3	50	II 4 896.8	200
II 2 549.0	50	II 4 132.5	200	II 4 904.8	125
II 2 658.7	100	II 4 134.2	50	II 4 917.7	125
II 2 672.2	50	II 4 141.4	60	II 4 970.1	50
II 2 677.0	150	II 4 291.8	50	II 4 995.5	60
II 2 688.0	150	II 4 307.4	75	II 5 078.3	150
II 3 092.2	50	II 4 309.1	50	II 5 099.3	100
II 3 316.9	50	II 4 343.6	100	II 5 103.0	125
II 3 329.1	150	II 4 372.9	80	II 5 217.9	100
II 3 353.4	125	II 4 569.4	50	II 5 423.3	150
II 3 798.8	50	II 4 572.1	100	II 5 423.5	100
II 3 805.2	75	II 4 740.4	150	II 5 443.4	100
II 3 820.3	100	II 4 755.6	50	II 5 444.3	60
II 3 827.6	150	II 4 768.7	150	II 5 456.3	50
II 3 843.3	100	II 4 781.8	50	II 5 457.0	75
II 3 845.4	50	II 4 785.4	50	II 6 094.7	100
II 3 845.7	75	II 4 794.5	250	II 6 661.7	75
II 3 851.0	100	II 4 810.1	200	I 7 256.7	200
II 3 860.8	150	II 4 819.5	200	I 7 414.1	150
II 3 861.0	100				

TABLE VIII (*Continued*)

Principal Lines by Elements (*Discharge Spectrum*)

FLUORINE

F

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
II 3 060.0	60	II 4 103.1	150	6 774.0	100
3 078.8	350	II 4 103.5	300	I 6 795.5	60
II 3 202.7	200	II 4 103.7	50	I 6 834.3	300
II 3 501.4	200	II 4 103.9	50	I 6 856.0	1000
II 3 503.0	60	II 4 109.2	100	I 6 870.2	150
II 3 503.1	400	II 4 116.5	50	I 6 902.5	500
II 3 505.6	600	II 4 119.2	50	I 6 909.8	150
II 3 541.8	100	II 4 207.2	50	I 6 966.4	70
II 3 541.9	60	II 4 246.3	300	I 7 037.5	200
3 577.2	60	II 4 275.2	100	I 7 128.0	150
3 602.9	60	II 4 299.2	150	I 7 202.4	125
II 3 642.0	60	II 4 446.7	150	I 7 311.0	125
II 3 704.5	60	II 4 447.2	200	I 7 332.0	200
II 3 847.1	800	II 4 859.4	50	I 7 398.7	400
II 3 850.0	600	I 6 239.6	300	I 7 425.6	150
II 3 851.7	200	I 6 348.5	200	I 7 482.7	80
II 4 024.7	500	I 6 413.7	150	I 7 489.1	50
II 4 025.0	150	I 6 569.7	50	I 7 754.7	60
II 4 025.5	300	I 6 690.5	60	I 7 800.2	50

HELIUM

He

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
II 2 511.2	50	I 3 888.6	1000	I 5 015.7	100
II 2 533.3	100	I 3 964.7	50	II 5 411.6	50
I 2 945.1	100	I 4 026.2	70	I 5 875.6	1000
I 3 187.7	200	I 4 471.5	100	II 6 560.1	100
II 3 203.1	100	II 4 685.8	300	I 6 678.1	100
I 3 819.6	50	I 4 921.9	50	I 7 065.2	70

HYDROGEN

H

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
I 3 889.1	60	I 4 340.5	200	6 562.7	1000
I 4 101.7	100	4 861.3	500	6 562.8	2000

TABLE VIII (*Continued*)

PRINCIPAL LINES BY ELEMENTS (*Discharge Spectrum*)

IODINE

I

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
2 034.9	100	II 4 676.9	80	I 6 339.0	100
2 049.5	150	I 4 763.4	80	6 339.5	300
2 062.4	900	I 4 862.3	700	II 6 340.0	100
2 169.6	100	I 4 917.0	100	6 348.3	50
2 230.0	400	I 5 119.3	500	I 6 359.2	60
2 250.0	100	II 5 161.2	300	I 6 367.3	70
II 2 335.5	60	I 5 204.2	50	I 6 371.8	100
2 342.4	150	I 5 234.6	80	6 440.2	100
2 408.0	60	II 5 245.7	80	I 6 444.5	100
2 419.2	60	I 5 296.5	150	6 475.9	70
2 444.1	60	I 5 309.5	200	I 6 488.2	150
II 2 461.1	60	II 5 338.2	300	I 6 538.3	70
II 2 464.7	100	5 345.1	300	I 6 566.5	400
2 494.7	100	II 5 407.4	60	6 583.8	70
II 2 499.3	60	I 5 427.1	50	II 6 585.2	70
II 2 503.0	150	II 5 435.8	125	I 6 619.7	200
II 2 531.0	60	5 464.6	900	6 661.2	100
II 2 533.6	100	I 5 491.6	100	6 662.1	100
2 561.5	150	II 5 496.9	900	II 6 666.0	70
II 2 564.4	70	II 5 504.7	60	I 6 697.3	90
II 2 566.3	300	5 600.3	50	6 698.5	50
II 2 582.8	400	II 5 625.7	150	6 727.0	70
II 2 593.5	150	I 5 678.1	80	6 732.1	150
2 627.0	60	II 5 710.5	150	6 736.6	50
2 635.3	60	II 5 738.3	50	6 738.1	70
2 674.8	60	I 5 764.3	100	I 6 739.5	50
2 689.0	100	I 5 894.1	60	I 6 741.6	50
II 2 698.3	50	6 007.5	50	I 6 773.6	50
2 712.2	100	6 015.9	50	I 6 788.9	100
2 730.1	50	I 6 024.1	300	I 6 789.3	50
2 872.9	60	I 6 048.7	70	I 6 801.0	50
II 2 878.6	400	II 6 068.9	50	I 6 812.2	50
2 993.9	70	II 6 075.0	80	II 6 812.6	100
3 055.4	350	I 6 082.5	1000	II 6 902.1	150
3 078.8	350	6 086.8	150	II 6 958.8	1000
3 081.7	100	I 6 125.5	100	7 018.3	50
3 194.0	100	II 6 127.5	125	II 7 018.9	50
3 686.5	70	6 132.9	50	II 7 034.0	70
3 688.2	125	I 6 192.0	150	7 042.2	70
3 724.8	50	6 195.5	100	I 7 063.6	50
3 931.0	400	I 6 200.5	50	7 085.2	150
I 3 940.2	500	II 6 204.9	70	I 7 088.0	100
II 4 036.1	50	I 6 213.2	70	I 7 102.7	50
4 070.7	150	I 6 213.9	70	7 122.1	60
4 221.0	80	6 229.4	50	II 7 139.0	70
II 4 409.0	250	6 232.9	50	I 7 142.1	100
II 4 423.8	80	6 236.4	50	I 7 236.8	150
II 4 452.9	700	6 280.3	50	I 7 300.3	50
II 4 473.4	80	I 6 294.1	300	II 7 351.4	60
II 4 476.1	60	I 6 320.4	50	I 7 402.1	300
4 632.3	50	I 6 320.6	100	I 7 411.3	50
I 4 640.9	50	6 320.8	50	7 416.6	50
I 4 666.7	50	I 6 330.5	50	I 7 469.0	500
II 4 675.5	50	6 338.0	100	I 7 490.6	70

TABLE VIII (*Continued*)

PRINCIPAL LINES BY ELEMENTS (*Discharge Spectrum*)

KRYPTON

Kr

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
2 353.7	50	II 4 185.1	50	II 4 691.3	100
II 2 464.8	100	II 4 236.6	100	II 4 694.4	200
II 2 592.5	60	II 4 250.6	150	II 4 695.7	50
II 2 712.4	80	II 4 252.7	50	II 4 739.0	3000
2 795.8	80	II 4 254.9	100	II 4 752.0	100
II 2 816.5	60	4 259.4	80	II 4 762.4	300
II 2 833.2	100	II 4 268.6	60	II 4 765.7	1000
II 2 967.3	80	II 4 268.8	100	II 4 796.3	60
II 3 150.9	80	I 4 274.0	1000	II 4 811.8	300
II 3 200.4	50	I 4 283.0	100	II 4 825.2	300
II 3 405.2	80	II 4 292.9	600	II 4 832.1	800
II 3 446.5	50	II 4 317.8	500	II 4 846.6	700
II 3 460.1	50	I 4 318.6	400	II 4 857.2	150
II 3 503.3	50	I 4 319.6	1000	II 4 915.9	100
II 3 589.7	70	II 4 323.0	150	II 4 945.6	300
II 3 607.9	100	II 4 331.2	80	II 4 948.5	50
II 3 631.9	200	II 4 355.5	3000	II 4 960.3	100
II 3 654.0	250	I 4 362.6	500	II 4 978.9	100
I 3 665.3	80	II 4 369.7	200	II 4 982.8	50
3 669.0	150	I 4 376.1	800	II 5 013.3	100
I 3 679.6	50	II 4 381.5	100	II 5 021.9	100
I 3 679.6	50	II 4 386.5	300	II 5 022.4	200
II 3 680.4	100	I 4 400.0	200	II 5 033.9	100
II 3 686.2	80	II 4 401.0	100	II 5 046.3	80
II 3 718.0	300	I 4 410.4	50	II 5 086.5	250
II 3 718.6	200	I 4 418.8	50	II 5 125.7	400
II 3 724.4	150	II 4 422.7	100	II 5 143.1	600
II 3 741.7	200	I 4 425.2	100	II 5 166.8	80
II 3 744.8	150	II 4 431.7	500	II 5 187.0	60
I 3 773.4	50	II 4 436.8	600	II 5 200.2	60
II 3 778.1	500	II 4 453.2	50	II 5 208.3	500
II 3 783.1	500	II 4 453.9	600	II 5 229.5	60
II 3 844.5	50	I 4 463.7	800	II 5 276.5	100
3 906.3	150	II 4 475.0	800	II 5 308.7	200
II 3 912.6	70	II 4 481.9	50	II 5 322.8	60
II 3 917.6	50	II 4 489.9	400	II 5 333.4	500
II 3 920.1	200	I 4 502.4	600	II 5 346.8	60
II 3 954.8	90	II 4 523.1	400	II 5 446.3	80
II 3 994.8	100	II 4 556.6	200	II 5 468.2	200
II 3 998.0	100	II 4 577.2	800	I 5 490.9	50
II 4 037.8	30	II 4 582.9	300	II 5 499.5	50
II 4 044.7	80	II 4 592.8	150	I 5 500.7	50
II 4 050.4	50	II 4 598.5	50	II 5 522.9	60
II 4 065.1	300	II 4 604.0	60	II 5 553.0	100
II 4 088.3	500	II 4 610.7	60	I 5 562.2	500
II 4 098.7	250	II 4 615.3	500	II 5 568.7	100
II 4 109.2	100	II 4 619.2	1000	I 5 570.3	2000
4 138.0	50	II 4 633.9	800	I 5 580.4	80
4 139.1	100	II 4 658.9	2000	II 5 633.0	100
II 4 145.1	250	II 4 680.4	500	I 5 649.6	100

TABLE VIII (*Continued*)

PRINCIPAL LINES BY ELEMENTS (*Discharge Spectrum*)

KRYPTON (*Continued*)

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
I 5 672.5	50	I 6 456.3	200	I 7 486.9	100
II 5 681.9	400	II 6 470.9	50	II 7 524.5	300
II 5 690.4	200	II 6 570.1	150	I 7 587.4	1000
II 5 771.4	100	II 6 763.6	100	I 7 601.5	5000
I 5 832.9	100	II 6 764.4	80	II 7 641.2	150
I 5 866.8	50	II 6 771.2	50	I 7 685.2	1000
I 5 870.9	3000	I 6 813.1	50	I 7 694.5	1000
I 5 879.9	50	I 6 904.7	100	II 7 735.7	200
II 5 892.2	200	II 7 074.0	60	I 7 746.8	150
I 5 993.9	60	II 7 213.1	250	7 782.0	100
I 6 012.2	50	I 7 224.1	100	I 7 806.5	50
I 6 056.1	60	I 7 287.3	80	I 7 854.8	800
II 6 168.8	50	II 7 289.8	400	I 7 913.4	200
II 6 303.7	100	II 7 407.0	400	I 7 928.6	150
II 6 416.6	60	I 7 425.5	60	I 7 982.4	100
II 6 420.2	300	II 7 435.7	200	II 7 993.2	50
I 6 421.0	100				

TABLE VIII (*Continued*)

PRINCIPAL LINES BY ELEMENTS (*Discharge Spectrum*)

NEON

Ne

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
2 595.2	50	I 3 447.7	150	II 4 290.4	100
I 2 613.6	30	I 3 450.8	50	I 4 306.2	70
I 2 616.6	25	I 3 460.5	75	I 4 314.7	30
I 2 636.0	25	I 3 464.3	75	I 4 334.1	70
2 645.5	50	I 3 466.6	150	I 4 336.2	50
I 2 645.7	35	II 3 482.0	25	I 4 363.5	70
I 2 647.4	150	I 3 498.1	75	II 4 369.8	70
I 2 648.6	25	I 3 501.2	150	I 4 372.2	30
2 651.0	50	I 3 510.7	50	II 4 379.5	100
I 2 675.2	150	I 3 520.5	1000	I 4 381.2	30
II 2 792.1	25	II 3 542.9	40	II 4 391.9	150
I 2 795.1	35	II 3 568.5	25	I 4 395.6	50
I 2 872.7	35	I 3 593.5	500	II 4 397.9	100
I 2 913.2	150	I 3 593.6	250	II 4 409.3	150
I 2 932.7	75	I 3 600.2	75	II 4 413.2	50
I 2 947.3	150	I 3 609.2	50	I 4 421.6	50
II 2 955.7	40	I 3 633.7	75	I 4 422.5	300
I 2 974.7	250	I 3 664.1	250	I 4 424.8	300
I 2 975.5	35	I 3 682.2	75	I 4 425.4	150
I 2 980.6	40	I 3 685.7	75	I 4 427.8	30
I 2 980.9	50	II 3 694.2	250	II 4 428.5	100
I 2 982.7	250	3 701.2	40	II 4 430.9	50
I 2 992.4	150	II 3 709.6	40	I 4 433.7	70
II 3 001.7	25	II 3 713.1	250	II 4 442.7	30
I 3 012.1	50	II 3 727.1	125	II 4 457.0	70
I 3 013.0	50	II 3 734.9	40	I 4 460.2	100
I 3 030.3	50	I 3 754.2	50	I 4 465.7	50
II 3 047.6	25	I 3 770.4	400	I 4 466.8	70
I 3 057.4	250	II 3 777.2	75	II 4 468.9	70
I 3 063.7	150	II 3 829.8	40	I 4 475.7	100
I 3 078.9	75	I 4 042.6	50	I 4 483.2	150
I 3 079.2	75	II 4 062.9	30	I 4 488.1	300
I 3 126.2	150	I 4 064.0	50	I 4 491.8	80
I 3 147.7	25	I 4 080.1	50	I 4 491.8	50
I 3 148.6	75	I 4 131.1	70	I 4 492.4	30
I 3 153.4	50	II 4 133.7	30	I 4 493.7	50
II 3 218.2	75	I 4 164.8	50	I 4 500.2	50
II 3 297.0	40	I 4 166.1	30	II 4 508.2	30
II 3 323.8	40	I 4 174.4	70	I 4 514.9	70
II 3 334.9	250	I 4 175.2	60	I 4 516.9	50
I 3 351.7	25	I 4 175.5	40	II 4 522.7	50
II 3 355.1	40	I 4 198.1	70	I 4 526.2	50
II 3 367.2	25	II 4 217.2	30	I 4 529.5	30
I 3 369.8	500	II 4 219.8	100	I 4 536.3	150
I 3 369.9	700	II 4 231.6	50	I 4 537.7	300
I 3 375.7	50	II 4 250.7	50	I 4 537.8	1000
II 3 388.5	25	I 4 268.0	70	I 4 538.3	300
I 3 417.9	500	I 4 269.7	70	I 4 539.2	50
I 3 418.0	50	I 4 270.2	50	I 4 540.4	50
I 3 423.9	50	I 4 275.6	70	I 4 544.5	50

TABLE VIII (*Continued*)

Principal Lines by Elements (*Discharge Spectrum*)

NEON (*Continued*)

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
I 4 552.6	30	I 4 750.7	30	I 5 037.8	500
II 4 553.2	50	I 4 751.8	30	I 5 074.2	35
I 4 554.8	40	I 4 752.7	1000	I 5 080.4	150
I 4 565.9	60	I 4 754.4	100	I 5 099.0	25
I 4 566.8	40	I 4 758.7	150	I 5 104.7	35
II 4 569.0	70	I 4 780.3	50	I 5 113.7	75
I 4 573.6	50	I 4 780.9	30	I 5 116.5	150
I 4 575.1	300	4 788.9	300	I 5 117.0	35
II 4 580.4	30	I 4 789.6	100	I 5 120.5	25
I 4 582.0	150	4 790.2	50	I 5 122.3	150
I 4 582.5	150	I 4 790.7	30	I 5 122.3	150
II 4 588.1	30	I 4 810.1	150	I 5 144.9	500
I 4 593.2	50	I 4 810.6	100	I 5 145.0	500
I 4 595.2	50	I 4 814.3	50	I 5 145.1	35
I 4 609.9	150	I 4 817.6	300	I 5 152.0	75
I 4 614.4	100	I 4 818.8	150	I 5 154.4	50
II 4 616.0	50	I 4 819.9	70	I 5 156.7	50
I 4 617.8	70	I 4 821.9	300	I 5 158.9	50
I 4 628.3	150	I 4 823.2	100	I 5 188.6	150
I 4 636.1	70	I 4 823.4	50	5 193.1	150
I 4 636.6	70	I 4 825.5	50	I 5 193.2	150
I 4 637.0	50	I 4 827.3	1000	I 5 203.9	150
I 4 639.6	30	I 4 827.6	300	I 5 208.9	70
I 4 640.4	70	I 4 837.3	500	I 5 210.6	50
I 4 644.8	40	I 4 842.9	50	I 5 214.3	35
I 4 645.4	300	I 4 851.5	60	I 5 222.4	50
I 4 649.9	70	I 4 852.7	100	I 5 234.0	50
I 4 653.7	50	I 4 863.1	100	I 5 274.0	40
I 4 656.4	300	I 4 864.4	30	I 5 280.4	60
I 4 661.1	150	I 4 865.5	100	I 5 298.2	150
I 4 663.1	40	I 4 866.5	80	I 5 304.8	70
I 4 667.4	100	I 4 867.0	70	I 5 316.8	25
I 4 670.9	70	I 4 868.3	70	I 5 326.4	75
I 4 678.2	300	I 4 884.9	1000	I 5 330.8	600
I 4 678.6	50	I 4 885.1	100	I 5 333.3	50
I 4 679.1	150	I 4 892.1	500	I 5 341.1	1000
I 4 680.4	100	I 4 897.9	70	I 5 343.3	600
I 4 681.2	50	I 4 899.0	50	I 5 349.2	150
I 4 683.8	30	I 4 928.2	70	I 5 355.2	150
I 4 687.7	100	I 4 930.9	50	I 5 355.4	150
I 4 702.6	150	I 4 939.0	100	I 5 360.0	150
I 4 704.4	1500	I 4 945.0	100	I 5 360.4	35
I 4 708.9	1200	I 4 955.4	150	I 5 362.2	25
I 4 710.5	30	I 4 957.0	1000	I 5 366.2	25
I 4 712.1	1000	I 4 957.1	150	I 5 375.0	50
4 713.1	100	I 4 974.8	50	+ I 5 400.562	2000
I 4 714.3	70	I 4 994.9	150	I 5 412.7	250
I 4 715.1	30	I 5 005.2	500	I 5 418.6	150
I 4 715.3	1500	I 5 005.3	50	I 5 420.2	50
I 4 717.6	70	I 5 022.9	25	I 5 433.6	250
I 4 725.1	70	I 5 031.3	250	I 5 448.5	150
I 4 749.6	300	I 5 036.0	35	I 5 494.4	50

TABLE VIII (*Continued*)

PRINCIPAL LINES BY ELEMENTS (*Discharge Spectrum*)

NEON (*Continued*)

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
I 5 507.3	25	I 5 934.5	75	+ I 6 304.789	100
I 5 533.7	75	I 5 939.3	50	I 6 313.7	150
I 5 538.6	50	+ I 5 944.834	500	I 6 328.2	300
I 5 562.4	150	I 5 961.6	70	I 6 330.9	150
I 5 562.8	500	I 5 965.5	500	+ I 6 334.428	1000
I 5 563.0	75	I 5 966.2	35	I 6 351.9	100
I 5 576.0	35	I 5 974.6	500	I 6 365.0	100
I 5 589.4	50	+ I 5 975.534	600	+ I 6 382.991	1000
I 5 652.6	75	I 5 987.9	150	I 6 401.1	100
I 5 656.0	75	I 5 991.7	75	I 6 402.2	2000
I 5 656.7	500	I 6 001.0	100	I 6 421.7	100
I 5 662.5	75	+ I 6 029.997	1000	I 6 444.7	150
I 5 684.6	25	I 6 046.2	50	+ I 6 506.528	1000
I 5 689.8	150	I 6 064.6	50	II 6 511.0	100
I 5 718.9	150	+ I 6 074.338	1000	+ I 6 532.882	100
I 5 719.2	500	+ I 6 096.163	300	+ I 6 598.953	1000
I 5 719.5	75	I 6 128.5	100	I 6 602.9	100
I 5 748.3	500	I 6 142.5	100	I 6 652.1	150
I 5 748.7	70	I 6 143.1	1000	I 6 666.9	100
II 5 753.0	60	I 6 150.3	100	I 6 678.3	500
I 5 760.6	70	6 154.1	70	+ I 6 717.043	70
I 5 764.4	700	I 6 156.1	50	I 6 738.1	70
I 5 770.3	50	+ I 6 163.594	1000	I 6 929.5	1000
I 5 804.1	75	I 6 174.9	70	I 7 024.1	500
I 5 804.4	500	I 6 175.3	50	+ I 7 032.413	1000
I 5 811.4	300	I 6 182.1	150	I 7 051.3	70
I 5 816.6	50	I 6 189.1	70	I 7 059.1	200
I 5 820.2	500	I 6 193.1	50	+ I 7 173.939	1000
I 5 828.9	75	I 6 205.8	100	+ I 7 245.167	1000
+ I 5 852.488	2000	I 6 213.9	150	I 7 304.8	30
I 5 868.4	75	I 6 217.3	1000	I 7 438.9	300
I 5 872.1	75	I 6 225.7	50	I 7 472.4	50
+ I 5 881.895	1000	I 6 246.7	100	I 7 488.9	500
I 5 902.5	50	I 6 258.8	100	+ I 7 535.775	300
I 5 906.4	50	+ I 6 266.495	1000	I 7 544.0	100
I 5 913.6	250	I 6 273.0	70	I 7 839.1	30
I 5 918.9	250	I 6 276.0	50	I 7 937.0	70
I 5 922.9	25	I 6 293.8	100	I 7 943.2	200

PHOSPHORUS, *see page 532*
P

TABLE VIII (*Continued*)

Principal Lines by Elements (*Spark Spectrum*)

SELENIUM

Se

Wavelength	Spark	Wavelength	Spark	Wavelength	Spark
2.038.0	8	3 387.2	6	4 449.2	2
2.063.7p	8	3 514.0	8	4 467.6	3
2 073.0	3	3 544.2	10	4 516.2	2
2 354.3	3	3 637.5	10	4 563.9	4
2 459.5	3	3 711.6	6	4 604.3	5
2 591.4	5	3 738.7	10	4 618.7	3
2 630.9	5	3 800.9	8	4 648.4	5
2 685.9	4	3 849.6	2	I 4 730.9P	....
2 767.4	3	3 877.3	4	I 4 739.1p	....
2 777.7	3	4 008.1	2	I 4 742.4p	....
2 837.2	4	4 046.7	2	4 763.6	2
2 880 4	3	4 083.2	3	4 840.5	1
2 914.9	3	4 108.8	3	4 844.8	1
2 951.7	3	4 169.0	3	4 975.7	....
3 038.7	2	4 176.0	10	4 992.9	1
3 069.9	2	4 182.0	10	5 031.3	....
3 094.3	3	4 280.3	2	5 068.6	1
3 185.5	3	4 320.4	3	5 096.5	1
3 225.9	3	4 382.8	6	5 142.1	1
3 323.1	3	4 401.0	3	5 176.0	2
3 379.8	3	4 446.0	8	5 227.5	2

SULFUR, *see page 557*

S

TABLE VIII (*Continued*)

Principal Lines by Elements (*Discharge Spectrum*)

XENON

Xe

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
2 475.9	50	II 4 540.9	200	II 5 012.8	50
II 2 864.7	100	II 4 545.2	200	I 5 028.3	200
II 2 895.2	80	II 4 555.9	100	II 5 044.9	100
II 2 979.3	100	II 4 577.1	100	II 5 080.6	500
II 3 121.9	150	I 4 582.7	300	I 5 084.0	25
II 3 366.7	150	II 4 585.5	200	II 5 122.4	150
II 3 461.3	50	II 4 592.1	150	II 5 125.7	50
II 3 907.9	50	II 4 603.0	300	II 5 178.8	50
I 3 948.2	60	II 4 611.9	700	II 5 188.1	100
I 3 950.9	125	II 4 615.1	50	II 5 191.4	200
I 3 967.5	200	II 4 615.5	100	II 5 192.1	50
II 4 037.3	50	II 4 617.5	50	5 247.8	50
II 4 037.6	100	I 4 624.3	1000	II 5 260.4	300
II 4 057.5	100	II 4 651.9	100	II 5 262.0	200
I 4 078.8	100	II 4 668.5	50	II 5 268.3	50
II 4 098.9	50	I 4 671.2	2000	II 5 292.2	800
I 4 109.7	60	II 4 672.2	50	II 5 309.3	150
I 4 116.1	80	4 676.5	100	II 5 313.9	500
II 4 158.0	100	I 4 691.0	100	II 5 339.4	500
II 4 180.1	500	I 4 697.0	300	II 5 363.3	80
4 193.2	200	II 4 698.0	150	II 5 368.1	100
I 4 193.5	150	II 4 715.2	80	I 5 392.8	100
I 4 203.7	50	II 4 731.2	50	II 5 419.2	1000
II 4 208.5	200	I 4 734.2	600	II 5 439.0	400
II 4 209.5	100	II 4 769.1	100	II 5 445.5	80
II 4 213.7	200	II 4 773.2	50	II 5 450.5	100
II 4 215.6	100	II 4 779.2	50	II 5 460.4	200
II 4 223.0	200	II 4 787.8	50	II 5 472.6	500
II 4 238.3	200	I 4 792.6	150	II 5 531.3	300
II 4 245.4	200	I 4 807.0	500	I 5 552.4	80
II 4 251.6	50	II 4 818.0	100	I 5 566.6	100
II 4 296.4	200	II 4 823.4	150	5 572.2	50
II 4 310.5	200	I 4 829.7	400	I 5 581.8	50
II 4 330.5	500	I 4 843.3	300	II 5 591.6	50
4 369.2	100	II 4 844.3	1000	II 5 616.7	150
II 4 373.8	50	II 4 862.5	400	I 5 618.9	80
I 4 383.9	100	II 4 876.5	200	II 5 659.4	150
I 4 385.8	70	II 4 883.5	300	II 5 667.6	300
II 4 393.2	200	II 4 884.2	50	I 5 695.8	100
4 395.8	200	II 4 887.3	150	I 5 696.5	80
II 4 406.9	100	II 4 890.1	150	II 5 699.6	100
II 4 414.8	150	I 4 916.5	500	I 5 715.7	70
II 4 416.1	80	II 4 919.7	125	II 5 716.2	50
4 448.1	200	II 4 921.5	500	I 5 716.3	80
4 462.2	500	I 4 923.2	500	II 5 719.6	100
II 4 480.9	200	4 971.7	100	II 5 726.9	200
I 4 501.0	500	II 4 972.7	200	II 5 751.0	200
II 4 524.2	100	I 4 973.5	100	II 5 758.7	150
II 4 524.7	400	II 4 988.8	150	II 5 776.4	150
II 4 532.5	100	II 4 991.2	50	I 5 814.5	60

TABLE VIII (*Continued*)

PRINCIPAL LINES BY ELEMENTS (*Discharge Spectrum*)

XENON (*Continued*)

Wavelength	Geissler Tube	Wavelength	Geissler Tube	Wavelength	Geissler Tube
II 5 816.0	50	II 6 300.9	125	II 6 910.2	50
I 5 823.9	300	I 6 318.1	500	I 6 925.5	100
I 5 824.8	150	II 6 344.0	200	I 6 935.6	50
II 5 835.5	50	II 6 356.4	300	6 942.1	400
I 5 875.0	100	II 6 375.3	80	I 6 976.2	100
II 5 893.3	150	II 6 398.0	50	II 6 990.9	700
I 5 895.0	100	I 6 469.7	300	II 7 082.2	100
II 5 905.1	100	I 6 472.8	150	I 7 119.6	500
I 5 931.2	80	I 6 487.8	125	II 7 140.0	60
I 5 934.2	100	I 6 498.7	100	7 147.5	50
II 5 945.5	200	I 6 504.2	200	II 7 149.0	150
II 5 971.1	150	II 6 512.8	150	II 7 164.8	300
II 5 976.5	800	II 6 528.7	100	I 7 257.9	60
II 6 008.9	100	I 6 533.2	100	I 7 285.3	60
II 6 036.2	500	I 6 554.2	50	II 7 301.8	100
II 6 051.2	700	I 6 595.6	100	I 7 316.3	70
II 6 093.6	150	II 6 597.3	200	I 7 321.5	80
II 6 097.6	600	II 6 598.8	50	I 7 336.5	50
II 6 101.4	200	II 6 620.0	100	II 7 339.3	150
II 6 115.1	50	I 6 632.5	50	I 7 386.0	100
II 6 146.5	50	I 6 667.0	60	I 7 393.8	150
I 6 163.7	90	I 6 668.9	150	II 7 548.5	150
I 6 163.9	80	II 6 694.3	200	I 7 584.7	200
I 6 178.3	150	I 6 699.2	60	II 7 618.6	50
I 6 179.7	125	I 6 702.3	50	I 7 642.0	500
I 6 182.4	300	I 6 728.0	200	I 7 643.9	100
II 6 194.1	250	I 6 777.6	50	II 7 670.7	100
I 6 198.3	100	II 6 788.7	80	II 7 787.0	50
I 6 200.9	60	II 6 790.4	50	I 7 802.7	100
6 206.2	100	II 6 805.7	400	I 7 881.3	100
I 6 261.2	50	I 6 827.3	200	7 887.4	300
II 6 270.8	250	I 6 846.6	60	7 942.5	50
II 6 277.5	200	I 6 848.8	50	I 7 967.3	500
II 6 284.4	50	I 6 866.8	50	7 981.1	50
I 6 286.0	100	I 6 872.1	700	7 992.3	50
I 6 292.6	50	I 6 882.2	300		

TABLE IX

FRAUNHOFER LINES IN THE SUN'S SPECTRUM

(A80, A52, A48, A36)

WAVELENGTHS OF THE FRAUNHOFER LINES

Line	Due to	Wavelength	Line	Due to	Wavelength	Line	Due to	Wavelength
U	Fe	2 947.9	N	Fe	3 581.21	b_4	Fe	5 167.51
t	Fe	2 994.4	M	Fe	3 727.64		Mg	5 167.33
T	Fe	3 021.07	L	Fe	3 820.44	b_2	Mg	5 172.70
s	Fe	3 047.62	K	Ca	3 933.68	b_1	Mg	5 183.62
S_1	Fe	3 100.68	H	Ca	3 968.49	E_2	Fe	3 269.56
S_2	Fe	3 100.32	h	H	4 101.75	D_2	Na	5 889.98
	Fe	3 099.94	g	Ca	4 226.74	D_1	Na	5 895.94
R	Ca	3 181.28	G	Fe	4 307.91	C	H	6 562.82
	Ca	3 179.34		Ca	4 307.75	B	O	6 869.96
Q	Fe	3 286.77	G′	H	4 340.48	A	O	7 621.
P	Ti	3 361.19	F	H	4 861.34		O	7 594.
O	Fe	3 441.02						

TABLE X

CONVERSION TABLES—WAVELENGTH—FREQUENCY

A. **Wavelength in mμ to frequency in f.** (Note that the table may also be read as frequency to wavelength, i.e., 500 mμ = 600 f, and 500 f = 600 mμ.)

To obtain wavenumber values (in cm⁻¹), divide frequency (in f) by 3 and multiply by 100. To obtain frequency values (in f) from wavenumber values (in cm⁻¹), divide the wavenumber by 100 and multiply by 3.

	0	1	2	3	4	5	6	7	8	9
200	1500.0	1492.5	1485.1	1477.8	1470.6	1463.4	1456.3	1449.3	1442.3	1435.4
210	1428.6	1421.8	1415.1	1408.5	1401.9	1395.3	1388.9	1382.5	1376.1	1369.9
220	1363.6	1357.5	1351.4	1345.3	1339.3	1333.3	1327.4	1321.6	1315.8	1310.0
230	1304.3	1298.7	1293.1	1287.6	1282.1	1276.6	1271.2	1265.8	1260.5	1255.2
240	1250.0	1244.8	1239.7	1234.6	1229.5	1224.5	1219.5	1214.6	1209.7	1204.8
250	1200.0	1195.2	1190.5	1185.8	1181.1	1176.5	1171.9	1167.3	1162.8	1158.3
260	1153.8	1149.4	1145.0	1140.7	1136.4	1132.1	1127.8	1123.6	1119.4	1115.2
270	1111.1	1107.0	1102.9	1098.9	1094.9	1090.9	1087.0	1083.0	1079.1	1075.3
280	1071.4	1067.6	1063.8	1060.1	1056.3	1052.6	1049.0	1045.3	1041.7	1038.1
290	1034.5	1030.9	1027.4	1023.9	1020.4	1016.9	1013.5	1010.1	1006.7	1003.3
300	1000.0	996.7	993.4	990.1	986.8	983.6	980.4	977.2	974.0	970.9
310	967.7	964.6	961.5	958.5	955.4	952.4	949.4	946.4	943.4	940.4
320	937.5	934.6	931.7	928.2	925.9	923.1	920.2	917.4	914.6	911.9
330	909.1	906.3	903.6	900.9	898.2	895.5	892.9	890.2	887.6	885.0
340	882.4	879.8	877.2	874.6	872.1	869.6	867.1	864.6	862.1	859.6
350	857.1	854.7	852.3	849.9	847.5	845.1	842.7	840.3	838.0	835.7
360	833.3	831.0	828.7	826.4	824.2	821.9	819.7	817.4	815.2	813.0
370	810.8	808.6	806.5	804.3	802.1	800.0	797.9	795.8	793.7	791.6
380	789.5	787.4	785.4	783.3	781.3	779.2	777.2	775.2	773.2	771.2
390	769.2	767.3	765.3	763.4	761.4	759.5	757.6	755.7	753.8	751.9
400	750.0	748.1	746.2	744.6	742.6	740.7	738.9	737.1	735.3	733.5
410	731.7	729.9	728.2	726.4	724.5	722.8	721.0	719.4	717.7	715.9
420	714.3	712.6	710.8	709.2	707.5	705.8	704.2	702.5	700.9	699.3
430	697.7	696.1	694.4	692.7	691.2	689.7	688.0	686.5	684.9	683.4
440	681.8	680.3	679.7	677.2	675.7	674.2	672.6	670.1	669.6	668.2
450	666.7	665.2	663.7	662.2	660.8	659.3	657.9	656.5	655.0	653.6
460	652.2	650.8	649.4	647.9	646.6	645.2	643.7	642.4	641.0	639.7
470	638.3	636.9	635.6	634.2	632.9	631.6	630.2	628.9	627.6	626.3
480	635.0	623.7	622.4	621.1	619.8	618.6	617.3	616.0	614.8	613.5
490	612.2	611.0	609.8	608.5	607.3	606.1	604.8	603.6	602.4	601.2
500	600.0	598.8	597.6	596.4	595.2	594.1	592.9	591.7	590.6	589.4
510	588.2	587.1	585.9	584.8	583.6	582.5	581.4	580.3	579.2	578.0
520	576.9	575.8	574.7	573.6	572.5	571.4	570.3	569.3	568.2	567.1
530	566.0	565.0	563.9	562.9	561.8	560.7	559.7	558.7	557.6	556.6
540	555.6	554.5	553.5	552.5	551.5	550.5	549.5	548.4	547.4	546.4
550	545.5	544.5	543.5	542.5	541.5	540.5	539.5	538.6	537.6	536.6
560	535.7	534.8	533.8	532.9	531.9	531.0	530.0	529.1	528.2	527.2
570	526.3	525.4	524.5	523.6	522.6	521.7	520.8	519.9	519.0	518.1
580	517.2	516.4	515.5	514.6	513.7	512.8	511.9	511.0	510.2	509.3
590	508.5	507.6	506.8	505.9	505.0	504.2	503.3	502.5	501.7	500.8
600	500.0	499.2	498.3	497.5	496.7	495.9	495.0	494.2	493.4	492.6
610	491.8	491.0	490.2	489.4	488.6	487.8	487.0	486.2	485.4	484.7
620	483.9	483.1	482.3	481.5	480.7	480.0	479.5	478.5	477.7	476.9
630	476.2	475.4	474.7	473.9	473.2	472.4	471.7	471.0	470.2	469.4
640	468.7	468.0	467.3	466.6	465.8	465.1	464.4	463.7	463.0	462.2
650	461.5	460.8	460.1	459.4	458.7	458.0	457.3	456.6	455.9	455.2
660	454.6	453.9	453.2	452.5	451.8	451.1	450.5	449.8	449.1	448.4
670	447.7	447.1	446.4	445.7	451.1	444.4	443.8	443.1	442.4	441.8
680	441.2	440.5	439.9	439.2	438.6	438.0	437.3	436.6	436.0	435.4
690	434.8	434.2	433.5	432.9	432.3	431.7	431.0	430.4	429.8	429.2

TABLE X (*Continued*)

CONVERSION TABLES—WAVELENGTH—FREQUENCY

	0	1	2	3	4	5	6	7	8	9
700	428.6	428.0	427.4	426.7	426.1	425.5	424.9	424.3	423.7	423.1
710	422.5	421.9	421.3	420.8	420.2	419.6	419.0	418.4	417.8	417.2
720	416.7	416.1	415.5	514.9	414.4	413.8	413.2	412.7	412.1	411.5
730	411.0	410.4	409.8	409.3	408.7	408.2	407.6	407.1	406.5	406.0
740	405.4	404.9	404.3	403.8	403.2	402.7	402.1	401.6	401.1	400.5
750	400.0	399.5	398.9	398.4	397.9	397.4	396.8	396.3	395.8	395.3
760	394.7	394.2	393.7	393.2	392.7	392.2	391.6	391.1	390.6	390.1
770	389.6	389.1	388.6	388.1	387.6	387.1	386.6	386.1	385.6	385.1
780	384.6	384.1	383.6	383.1	382.7	383.2	381.7	381.2	380.7	380.2
790	379.7	379.3	378.8	378.3	377.8	377.4	376.9	376.4	375.9	375.4
800	375.0	374.5	374.0	373.6	373.1	372.7	372.2	371.7	371.3	370.8
810	370.4	369.9	369.5	369.0	368.6	368.1	367.6	367.2	366.7	366.3
820	365.9	365.4	365.0	364.5	364.1	363.6	363.2	362.8	362.3	361.9
830	361.4	361.0	360.6	360.1	359.7	359.3	358.9	358.4	358.0	357.6
840	357.1	356.7	356.3	355.9	355.5	355.0	354.6	354.2	353.8	353.4
850	352.9	352.5	352.1	351.7	351.3	350.9	350.5	350.1	349.7	349.2
860	348.8	348.4	348.0	347.6	347.2	346.8	346.4	346.0	345.6	345.2
870	344.8	344.4	344.0	343.6	343.2	342.9	342.5	342.1	341.7	341.3
880	340.9	340.5	340.1	339.8	339.4	339.0	338.6	338.2	337.8	337.5
890	337.1	336.7	336.3	335.9	335.6	335.2	334.8	334.4	334.1	333.7
900	333.3	333.0	332.6	332.2	331.9	331.5	331.1	330.8	330.4	330.0
910	329.7	329.3	328.9	328.6	328.2	327.9	327.5	327.2	326.8	326.4
920	326.1	325.7	325.4	325.0	324.7	324.3	324.0	323.6	323.3	322.9
930	322.6	322.2	321.9	321.5	321.2	320.9	320.5	320.2	319.8	319.5
940	319.1	318.8	318.5	318.1	317.8	317.5	317.1	316.8	316.5	316.1
950	315.8	315.5	315.1	314.8	314.5	314.1	313.8	313.5	313.2	312.8
960	312.5	312.2	311.9	311.5	311.2	310.9	310.6	310.2	309.9	309.6
970	309.3	309.0	308.6	308.3	308.0	307.7	307.4	307.1	306.7	306.4
980	306.1	305.8	305.5	305.2	304.9	304.6	304.3	304.0	303.6	303.3
990	303.0	302.7	302.4	302.1	301.8	301.5	301.2	300.9	300.6	300.3
1000	300.0	299.7	299.4	299.1	298.8	298.5	298.2	297.9	297.6	297.3
1010	297.0	296.7	296.4	296.1	295.9	295.6	295.3	295.0	294.7	294.4
1020	294.1	293.8	293.5	293.3	293.0	292.7	292.4	292.1	291.8	291.5
1030	291.3	291.0	290.7	290.4	290.1	289.9	289.6	289.3	289.0	288.7
1040	288.5	288.2	287.9	287.6	287.4	287.1	286.8	286.5	286.3	286.0
1050	285.7	285.4	285.2	284.9	284.6	284.4	284.1	283.8	283.6	283.3
1060	283.0	282.8	282.5	282.2	282.0	281.7	281.4	281.2	280.9	280.6
1070	280.4	280.1	279.8	279.6	279.3	279.1	278.8	278.6	278.3	278.0
1080	277.8	277.5	277.3	277.0	276.7	276.5	276.2	276.0	275.7	275.5
1090	275.2	275.0	274.7	274.5	274.2	274.0	273.7	273.5	273.2	273.0
1100	272.7	272.5	272.2	272.0	271.7	271.5	271.2	271.0	270.8	270.5
1110	270.3	270.0	269.8	269.5	269.3	269.1	268.8	268.6	268.3	268.1
1120	267.9	267.6	267.4	267.1	266.9	266.7	266.4	266.2	266.0	265.7
1130	265.5	265.3	265.0	264.8	264.6	264.3	264.1	263.9	253.6	263.4
1140	263.2	262.9	262.7	262.5	262.2	262.0	261.8	261.6	261.3	261.2
1150	260.9	260.6	260.4	260.2	260.0	259.7	259.5	259.3	259.1	258.8
1160	258.6	258.4	258.2	258.0	257.7	257.5	257.3	257.1	256.8	256.6
1170	256.4	256.2	256.0	255.8	255.5	255.3	255.1	254.9	254.7	254.4
1180	254.2	254.0	253.8	253.6	253.4	253.2	253.0	252.8	252.5	252.3
1190	252.1	251.9	251.7	251.5	251.3	251.1	250.8	250.6	250.4	250.2

PLATE XV

2735–2785 A

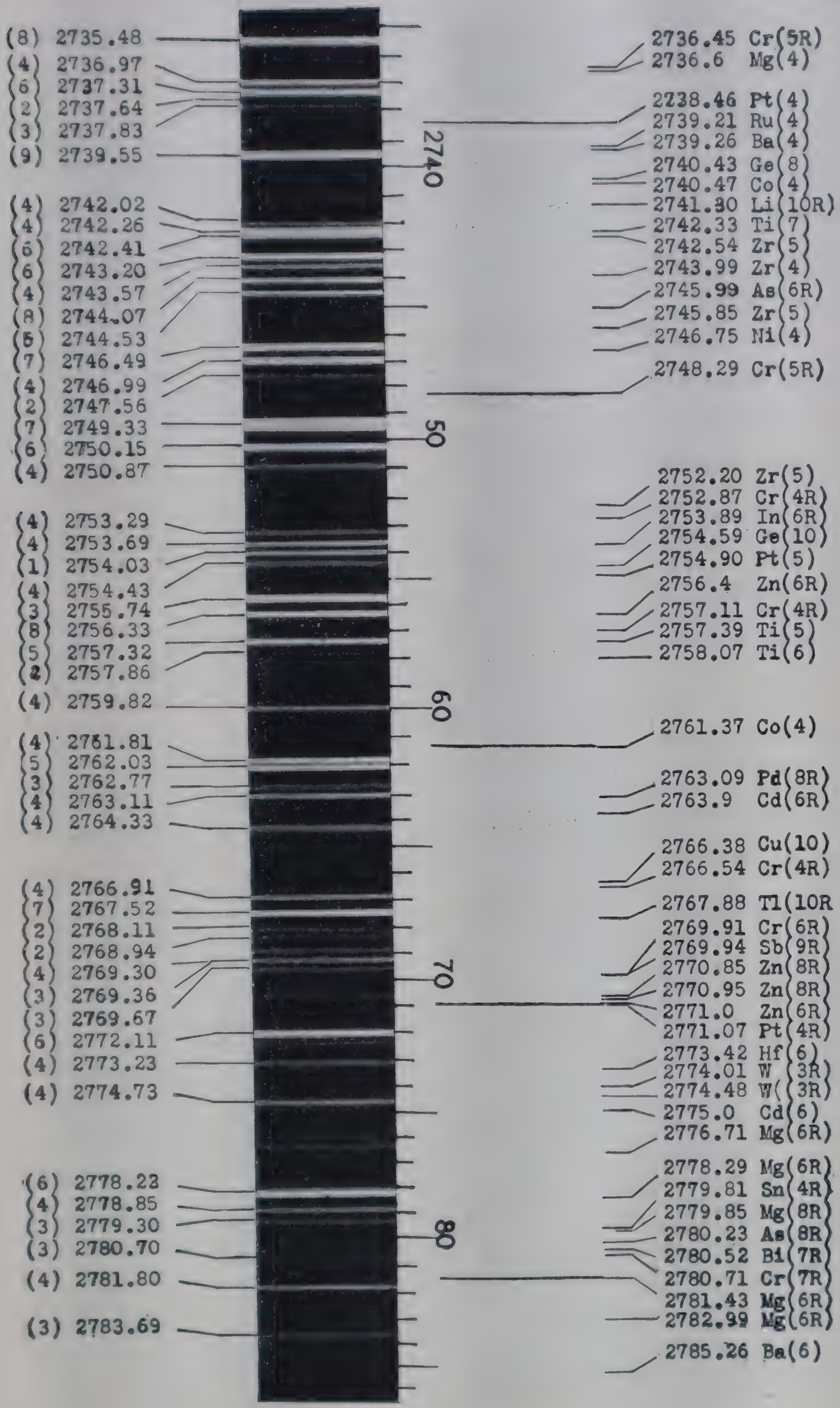


PLATE XVI

2785-2837

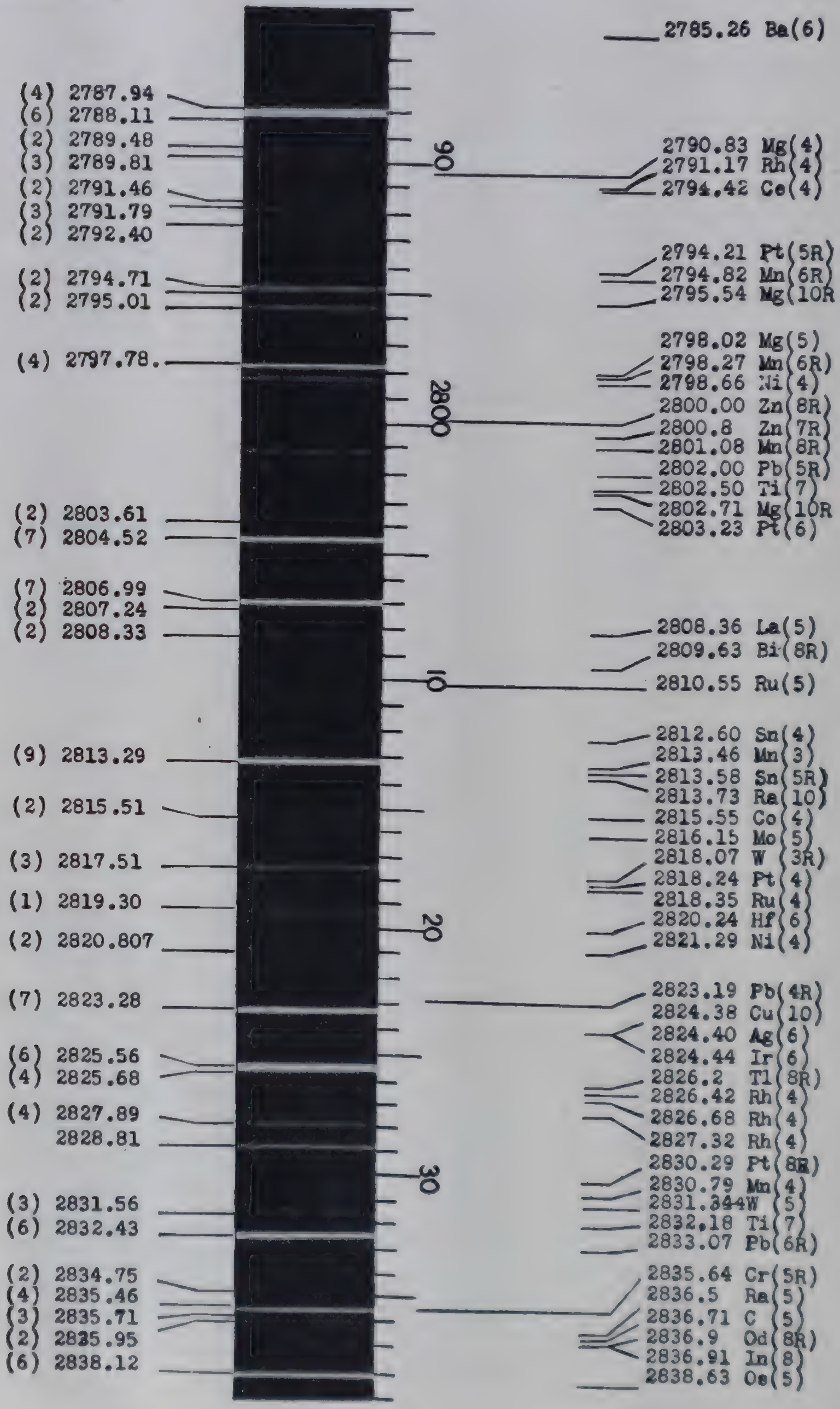


PLATE XVII

2838-2893 A

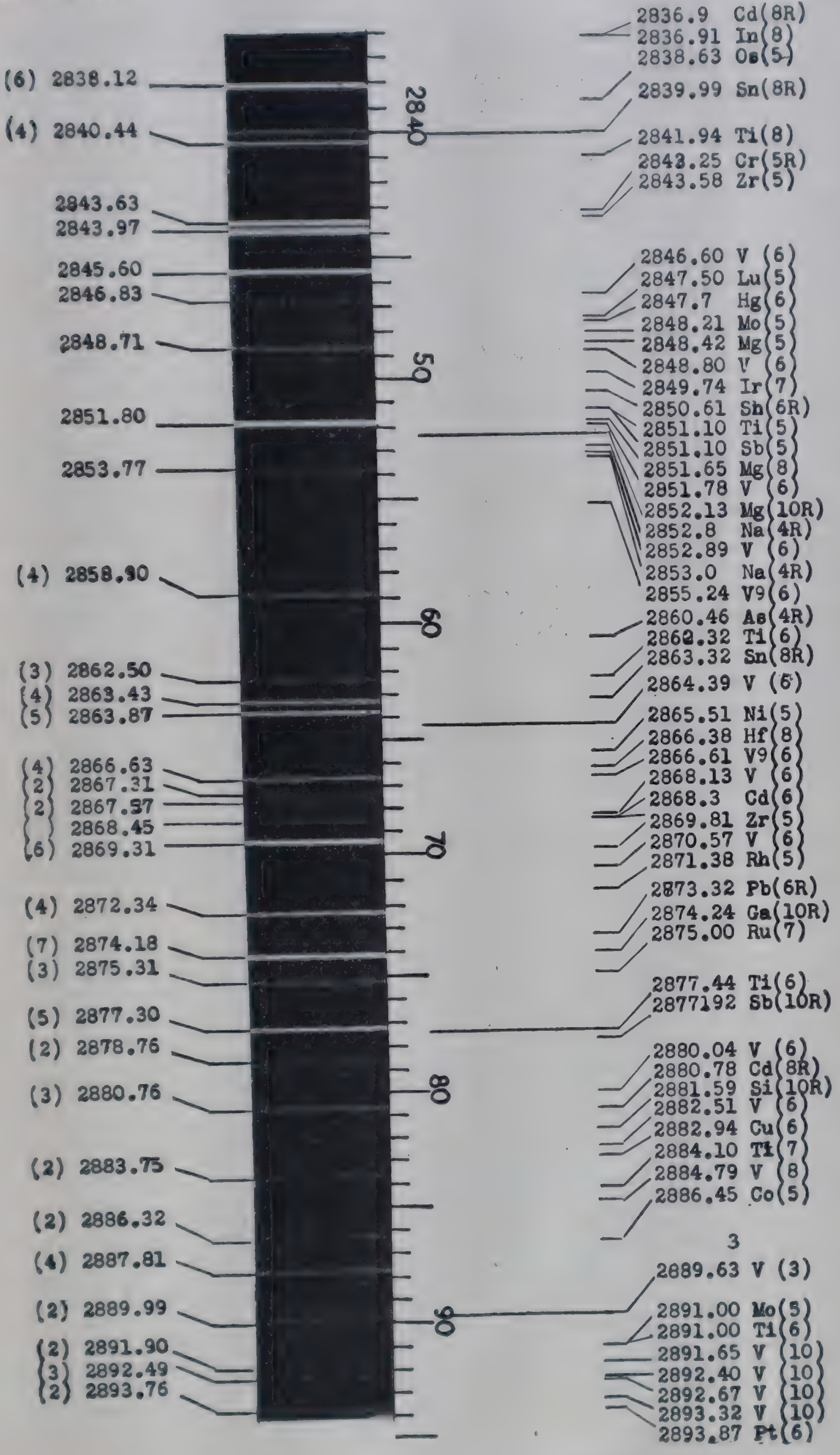


PLATE XVIII

2890–2950

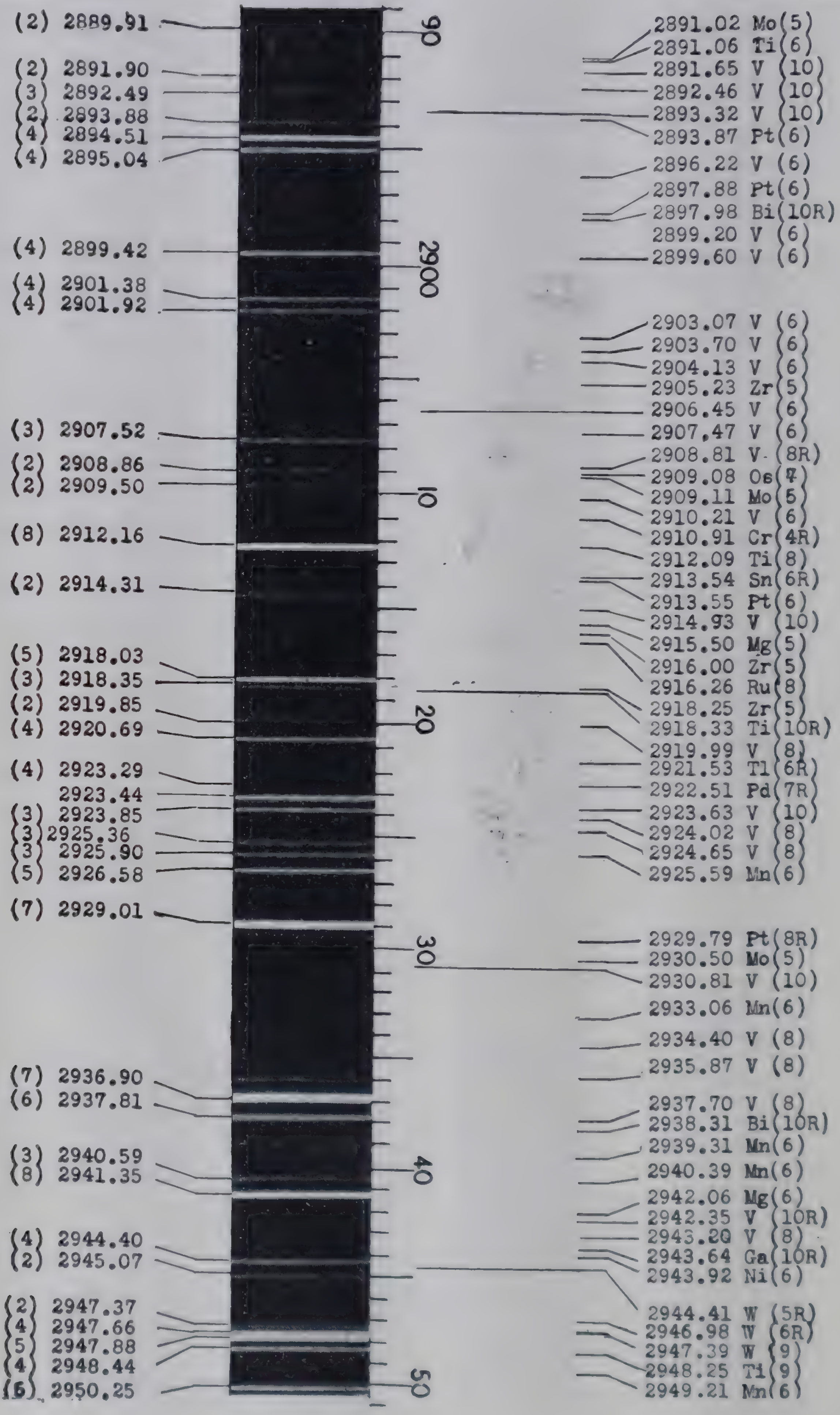


PLATE XIX

2947–3010 A

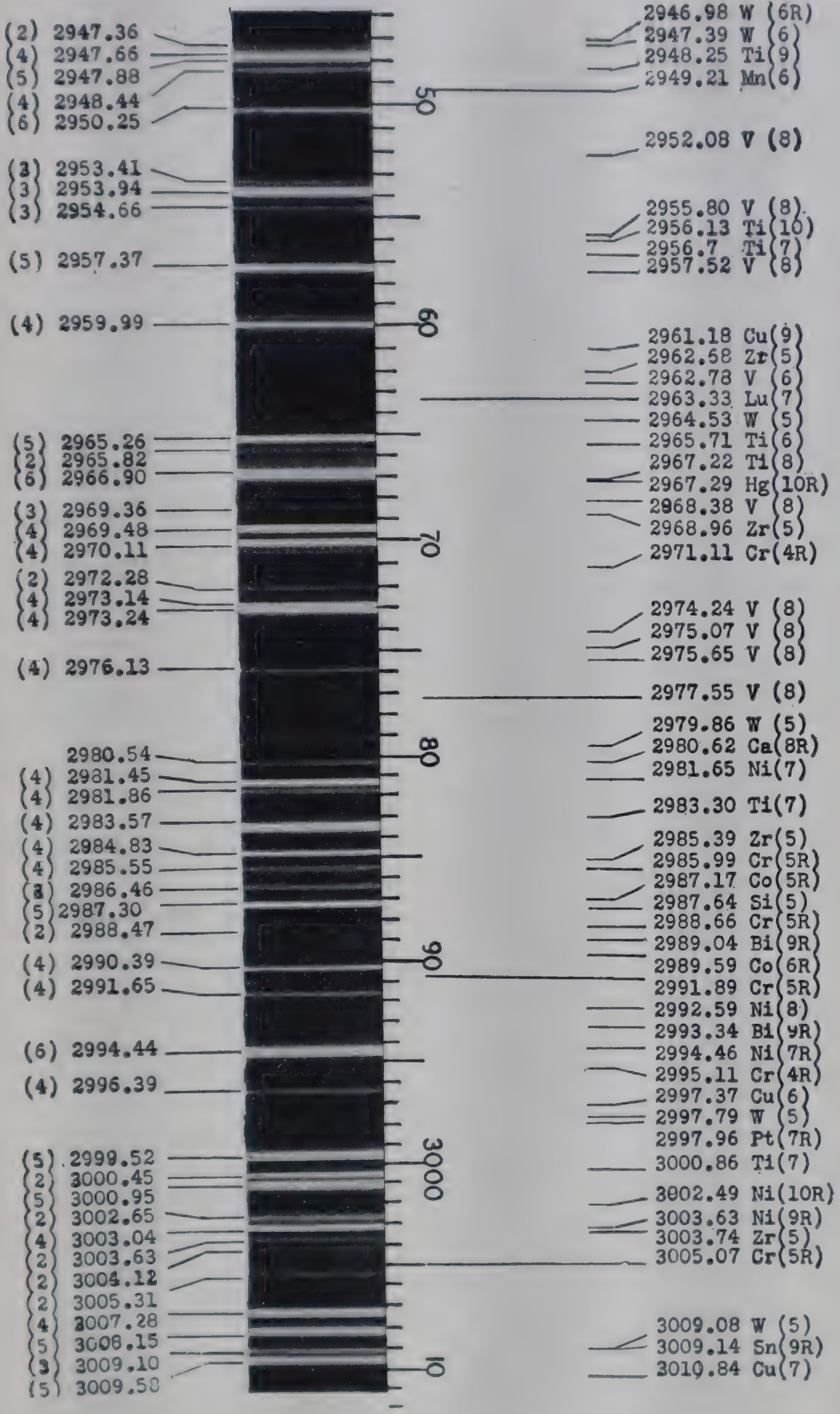


PLATE XX

3000–3067 A

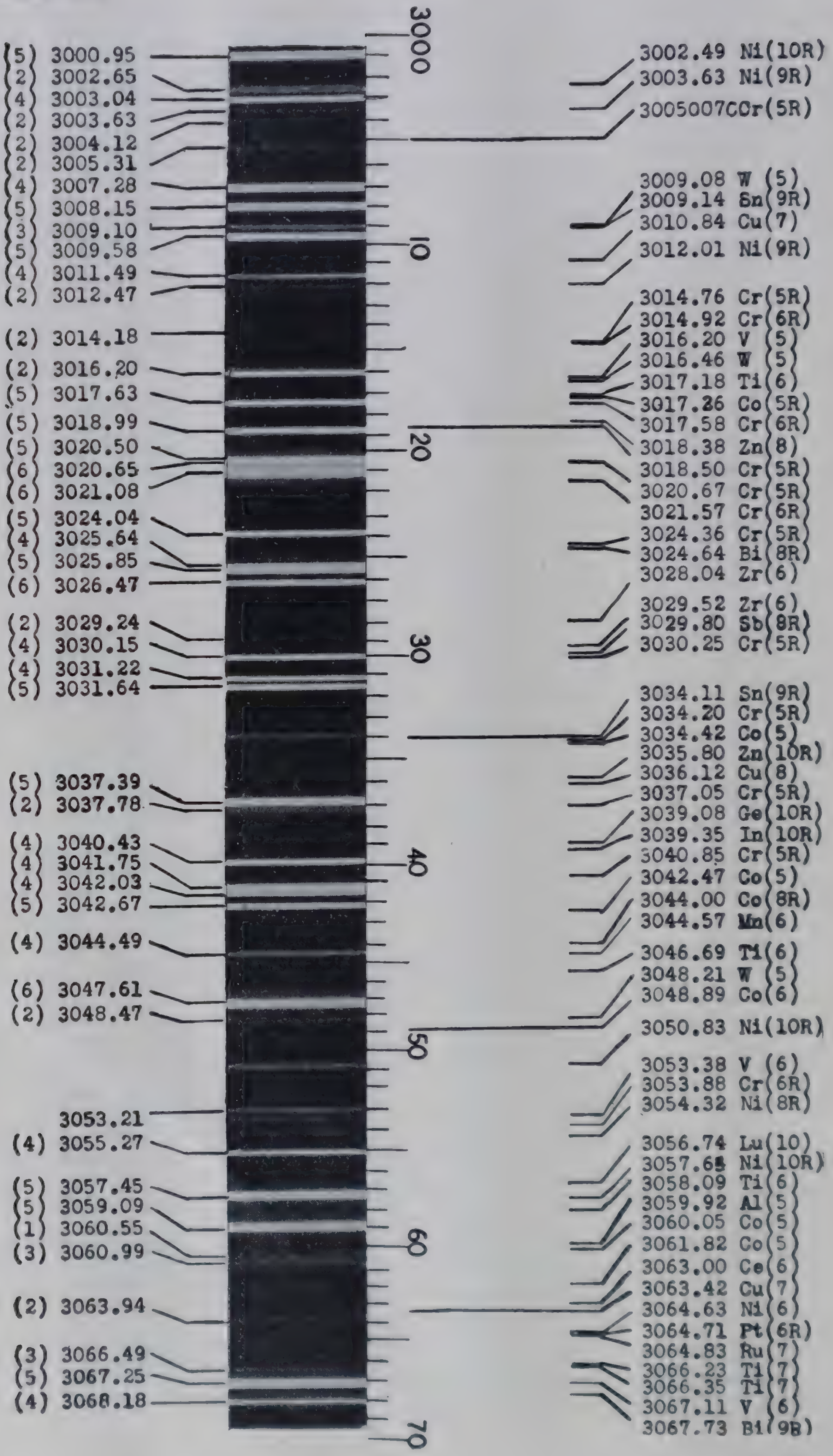


TABLE X (*Continued*)

CONVERSION TABLES—WAVELENGTH—FREQUENCY—WAVENUMBER

B. Photographic Range. Note that mμ and f are interconvertible (either column may be used and values of the other term read in the other column), but the relation between wavelength, frequency, and wavenumber must be read from left to right as indicated. Angstrom values are obtained by multiplying mμ values by 10.

λ or ν ⇄ ν or λ		
Wavelength mμ λ	ν ⇄ Frequency f	⇄ ν′ Wavenumber cm^{-1}
1500	200.0	6,667
1475	203.4	6,780
1450	206.9	6,897
1425	210.5	7,018
1400	214.3	7,143
1375	218.2	7,273
1350	222.2	7,407
1325	226.4	7,547
1300	230.8	7,692
1275	235.3	7,843
1250	240.0	8,000
1225	244.9	8,163
1200	250.0	8,333
1175	255.3	8,511
1150	260.9	8,696
1125	266.7	8,889
1100	272.7	9,091
1075	279.1	9,302
1050	285.7	9,524
1025	292.7	9,756
1000	300.0	10,000
975	307.7	10,256
950	315.9	10,526
925	324.3	10,811
900	333.3	11,111
875	342.9	11,429
850	352.9	11,765
825	363.6	12,121
800	375.0	12,500
775	387.1	12,903
750	400.0	13,333
725	413.8	13,793
700	428.6	14,286
675	444.4	14,815
650	461.5	15,385
625	480.0	16,000
600	500.0	16,667
575	521.7	17,391
550	545.5	18,182
525	571.4	19,048
500	600.0	20,000
475	631.6	21,053
450	666.7	22,222
440	681.8	22,727
430	697.7	23,256
420	714.3	23,810
410	731.7	24,390
400	750.0	25,000
390	769.2	25,641
380	789.5	26,316
370	810.8	27,027
360	833.3	27,778
350	857.1	28,571
340	882.4	29,412
330	909.1	30,303
320	937.5	31,250
310	967.7	32,258
300	1000.0	33,333
290	1034.5	34,483
280	1071.4	35,714
270	1111.1	37,037
260	1153.8	38,462
250	1200.0	40,000
240	1250.0	41,667
230	1304.3	43,478
220	1363.6	45,455
210	1438.5	47,619
200	1500.0	50,000

C. Correction for Refractive Index of Light in Air. If it is desirable to correct for the refractive index of light in air (reduce to vacuum conditions), the following additions to the wavelength value should be made prior to converting to wavenumber or frequency.

λ mμ	+n
1,000	0.2739
900	0.2468
800	0.2197
700	0.1927
600	0.1658
500	0.1391
400	0.1127
300	0.0872
200	0.0651

TABLE X (*Continued*)

Conversion Tables—Wavelength to Octaval (logarithm of wavelength)

D. The *octaval* system as devised by Shurcliff (*C182a*) is expressed in constant resolution unit (c.r.u.) in which the visible range of 375 to 750 mμ is chosen as the octave spacing. (See page 197.)

$$\text{Octaval (c.r.u.)} = 332.19 \log_{10} \text{ of wavelength in m}\mu - 655.07$$
$$= 100 (\log_2 \text{ of wavelength in m}\mu/375 \text{ m}\mu + 2)$$

a. The *octaval* scale bears a multiple relationship with respect to the wavelength scale as is indicated below:

Octaval (c.r.u.)	Wavelength (mμ)	Octaval (c.r.u.)	Wavelength (μ)
100	187.5	500	3
200	375	600	6
300	750	700	12
400	1500	800	24

b. Since each increase of 100 in the octaval scale results in doubling the wavelength value, only 100 c.r.u. units are included in the following table (i.e., from 200 to 300 c.r.u., which covers the wavelength range of 375 to 750 mμ).

To obtain values outside this range multiples are used as indicated in the following example:

The c.r.u. value for a wavelength of 910 mμ, is obtained by dividing the wavelength value by 2 (giving 455 mμ) and then adding 100 to the c.r.u. value as observed in the table for 455 mμ (288+100=328). For any wavelength conversion to octaval (c.r.u.) values one divides or multiplies the wavelength value by 2^n until the wavelength value is in the range covered in the table and then adds or subtracts (n×100) to the value obtained from the table. The reduction of c.r.u. values to wavelength values is accomplished by a reversal of this procedure.

Octaval (c.r.u.)	Wavelength (mμ)	Octaval (c.r.u.)	Wavelength (mμ)	Octaval (c.r.u.)	Wavelength (mμ)	Octaval (c.r.u.)	Wavelength (mμ)
200	375.00	226	449.04	251	534.00	276	635.06
201	377.60	227	452.16	252	537.72	277	639.46
202	380.24	228	455.32	253	541.46	278	643.92
203	382.88	229	458.48	254	545.22	279	648.40
204	385.54	230	461.68	255	549.02	280	652.90
205	388.22	231	464.88	256	552.84	281	657.44
206	390.92	232	468.12	257	556.68	282	662.00
207	393.64	233	471.36	258	560.56	283	666.60
208	396.38	234	474.66	259	564.46	284	671.26
209	399.14	235	477.96	260	568.38	285	675.94
210	401.90	236	481.28	261	572.34	286	680.62
211	404.70	237	484.64	262	576.32	287	685.36
212	407.52	238	488.00	263	580.32	288	690.12
213	410.26	239	491.38	264	584.36	289	694.82
214	413.22	240	497.80	265	588.42	290	699.76
215	416.08	241	498.26	266	592.50	291	704.64
216	418.98	242	501.72	267	596.64	292	709.52
217	421.88	243	505.20	268	600.80	293	714.46
218	424.82	244	508.72	269	604.96	294	719.42
219	427.78	245	512.26	270	609.18	295	724.42
220	430.76	246	515.82	271	613.42	296	729.48
221	433.74	247	519.40	272	617.68	297	734.56
222	436.76	248	523.02	273	621.98	298	739.66
223	439.80	249	526.66	274	626.30	299	744.80
224	442.86	250	530.32	275	630.66	300	750.00
225	445.94						

TABLE XI*A*

Conversion Tables

Transmission (T) to Extinction (E)

$$T = I_0/I_0,\ E = -\text{Log}_{10}\, I_0/I,\ T = -\text{Log}\, E$$

(% Transmission = Transmission × 100)

For transmission values below 0.1 or extinction values above 1.0 use 10, 100, or 1.000 times the transmission value as necessary to place it in the range of the table 0.1 to 1.0 and add to the extinction value a characteristic of 1, 2, 3, etc., as determined by the transmission multiplier.

For example:

Observed % transmission = 5.7%

$$\text{Transmission} = \frac{\%\ \text{Transmission}}{100} = 0.057$$

0.057 × 10 = 0.57 (multiplier of 10)
E for T of 0.57 = .244 (from table below)
E for T of 0.057 = 1.244 (characteristic of 1 from multiplier of 10)

T	Extinction (E)									
	0	1	2	3	4	5	6	7	8	9
0.10	1.00	.959	.920	.886	.854	.824	.796	.770	.745	.721
0.20	.699	.678	.658	.638	.620	.602	.585	.569	.553	.538
0.30	.528	.509	.495	.481	.468	.456	.444	.432	.420	.409
0.40	.398	.387	.377	.367	.357	.347	.337	.328	.319	.310
0.50	.301	.292	.284	.277	.268	.260	.252	.244	.237	.229
0.60	.222	.215	.208	.201	.194	.187	.180	.174	.168	.161
0.70	.155	.149	.143	.137	.131	.125	.119	.113	.108	.102
0.80	.097	.091	.086	.081	.076	.071	.066	.061	.056	.051
0.90	.046	.041	.036	.031	.027	.022	.018	.013	.009	.004
1.00	.000									

TABLE XI*B*

CONVERSION TABLES

(*B78, B69, B29, B46*)

Extinction (*E*)—Transmission percentage (*T* x 100)—Log extinction (log *E*)— Angular sector openings—Prism rotation

The 90° sector values are for rotating sectors of 90° opening as equivalent to 100 per cent. For sector with 180° maximum opening these values should be doubled. For transmissions of 10 per cent and les use 1/10 of the corresponding 100 per cent values.

The polarizing angle relation is based on

$$E=2\times\log\tan\theta \text{ (for a 45° extinction angle)}$$

log *E*	*E*	Percentage Transmitted	90° Sector Angle	Polarizing Angle (45° extinction)	log *E*	*E*	Percentage Transmitted	90° Sector Angle	Polarizing Angle (45° extinction)
−∞	0.00	100.0	90.0	45.0	−0.46	0.35	44.7	40.2	33.8
−2.00	0.01	97.8	88.0	44.7	−0.44	0.36	43.7	39.3	33.5
−1.70	0.02	95.5	86.0	44.3	−0.43	0.37	42.7	38.4	33.2
−1.52	0.03	93.3	84.0	44.0	−0.42	0.38	41.7	37.5	32.8
−1.40	0.04	91.2	82.1	43.7	−0.41	0.39	40.7	36.6	32.6
−1.30	0.05	89.1	80.2	43.3	−0.40	0.40	39.8	35.8	32.3
−1.22	0.06	87.0	78.3	43.0	−0.39	0.41	38.9	35.0	32.0
−1.16	0.07	85.1	76.6	42.7	−0.38	0.42	38.0	34.2	31.7
−1.10	0.08	83.1	74.8	42.4	−0.37	0.43	37.2	33.5	31.3
−1.05	0.09	81.2	73.0	42.0	−0.36	0.44	36.3	32.7	31.1
−1.00	0.10	79.4	71.5	41.7	−0.35	0.45	35.5	31.9	30.8
−0.96	0.11	77.6	69.9	41.4	−0.34	0.46	34.7	31.2	30.5
−0.92	0.12	75.8	68.3	41.1	−0.33	0.47	33.9	30.5	30.2
−0.89	0.13	74.2	66.8	40.8	−0.32	0.48	33.1	29.8	29.9
−0.85	0.14	72.5	65.3	40.4	−0.31	0.49	32.4	29.2	29.6
−0.82	0.15	70.8	63.8	40.4	−0.30	0.50	31.6	28.4	29.3
−0.80	0.16	69.2	62.3	39.6	−0.29	0.51	30.9	27.8	29.1
−0.77	0.17	67.6	60.8	39.4	−0.28	0.52	30.2	27.2	28.8
−0.75	0.18	66.1	59.5	39.0		0.53	29.5	26.6	28.5
−0.72	0.19	64.6	58.2	38.3	−0.27	0.54	28.8	25.9	28.3
−0.70	0.20	63.1	56.8	40.1	−0.26	0.55	28.2	25.4	28.0
−0.68	0.21	61.6	55.4	38.1	−0.25	0.56	27.5	24.8	27.7
−0.66	0.22	60.3	54.3	37.9		0.57	26.9	24.2	27.4
−0.64	0.23	59.0	53.1	37.5	−0.24	0.58	26.3	23.6	27.2
−0.62	0.24	57.6	51.9	37.2	−0.23	0.59	25.7	23.0	26.9
−0.60	0.25	56.3	50.7	36.8	−0.22	0.60	25.1	22.6	26.6
−0.59	0.26	55.0	49.5	36.6		0.61	24.5	22.1	26.3
−0.57	0.27	53.7	48.3	36.2	−0.21	0.62	24.0	21.6	26.1
−0.55	0.28	52.4	47.2	35.9	−0.20	0.63	23.4	21.1	25.8
−0.54	0.29	51.3	46.2	35.6		0.64	22.9	20.6	25.6
−0.52	0.30	50.1	45.1	35.3	−0.19	0.65	22.4	20.2	25.3
−0.51	0.31	49.0	44.2	35.0	−0.18	0.66	21.9	19.7	25.1
−0.50	0.32	47.9	43.2	34.7		0.67	21.4	19.3	24.8
−0.48	0.33	46.8	42.2	34.4	−0.17	0.68	20.9	18.8	24.6
−0.47	0.34	45.7	41.2	34.1	−0.16	0.69	20.4	18.4	24.3

TABLE XI*B* (*Continued*)

CONVERSION TABLES

log *E*	*E*	Percentage Transmitted	90° Sector Angle	Polarizing Angle (45° extinction)	log *E*	*E*	Percentage Transmitted	90° Sector Angle	Polarizing Angle (45° extinction)
	0.70	20.0	18.0	24.1	0.06	1.15	7.08		14.9
−0.15	0.71	19.5	17.6	23.8		1.16	6.92		14.7
	0.72	19.1	17.2	23.6		1.17	6.76		14.6
−0.14	0.73	18.6	16.8	23.3	0.07	1.18	6.61		14.4
−0.13	0.74	18.2	16.4	21.1		1.19	6.46		14.3
	0.75	17.8	16.0	22.9	0.08	1.20	6.31		14.1
−0.12	0.76	17.4	15.7	22.6		1.21	6.16		14.0
	0.77	17.0	15.3	22.4		1.22	6.03		13.8
−0.11	0.78	16.6	14.9	22.2	0.09	1.23	5.90		13.6
	0.79	16.2	14.6	21.9		1.24	5.76		13.5
−0.10	0.80	15.8	14.2	21.7		1.25	5.62		13.3
	0.81	15.5	13.9	21.5	0.10	1.26	5.50		13.2
−0.09	0.82	15.1	13.6	21.3		1.27	5.37		13.1
−0.08	0.83	14.8	13.3	21.0		1.28	5.24		12.9
	0.84	14.5	13.0	20.8	0.11	1.29	5.13		12.8
−0.07	0.85	14.2	12.8	20.6		1.30	5.01		12.6
	0.86	13.8	12.4	20.4		1.31	4.90		12.5
−0.06	0.87	13.5	12.1	20.2	0.12	1.32	4.79		12.3
	0.88	13.2	11.9	19.9		1.33	4.68		12.2
−0.05	0.89	12.9	11.6	19.7		1.34	4.57		12.1
	0.90	12.6	11.3	19.5	0.13	1.35	4.47		11.9
−0.04	0.91	12.3	11.1	19.3		1.36	4.37		11.8
	0.92	12.0	10.8	19.1		1.37	4.27		11.7
−0.03	0.93	11.7	10.5	18.9	0.14	1.38	4.17		11.5
	0.94	11.5	10.3	18.7		1.39	4.07		11.4
	0.95	11.2	10.1	18.5		1.40	3.98		11.3
−0.02	0.96	11.0	9.9	18.3	0.15	1.41	3.89		11.2
	0.97	10.7	9.6	18.1		1.42	3.80		11.0
−0.01	0.98	10.5	9.4	17.9		1.43	3.72		10.9
0.00	0.99	10.2	9.2	17.7		1.44	3.63		10.8
0.00	1.00	10.00		17.6	0.16	1.45	3.55		10.7
	1.01	9.78		17.4		1.46	3.47		10.6
0.01	1.02	9.55		17.2		1.47	3.39		10.5
	1.03	9.33		17.0	0.17	1.48	3.31		10.3
	1.04	9.12		16.8		1.49	3.24		10.2
0.02	1.05	8.91		16.6		1.50	3.16		10.1
	1.06	8.70		16.5	0.18	1.51	3.09		10.0
0.03	1.07	8.51		16.3		1.52	3.02		9.9
	1.08	8.31		16.1		1.53	2.95		9.7
	1.09	8.12		15.9		1.54	2.83		9.6
0.04	1.10	7.94		15.7	0.19	1.55	2.82		9.5
	1.11	7.76		15.6		1.56	2.75		9.4
0.05	1.12	7.58		15.4		1.57	2.69		9.3
	1.13	7.42		15.2	0.20	1.58	2.63		9.2
	1.14	7.25		15.1		1.59	2.57		9.1

TABLE XI*B* (*Continued*)

CONVERSION TABLES

log *E*	*E*	Percentage Transmitted	90° Sector Angle	Polarizing Angle (45° extinction)
	1.60	2.51		9.0
	1.61	2.45		8.9
0.21	1.62	2.40		8.8
	1.63	2.34		8.7
	1.64	2.29		8.6
	1.65	2.24		8.5
0.22	1.66	2.19		8.4
	1.67	2.14		8.3
	1.68	2.09		8.2
	1.69	2.04		8.1
0.23	1.70	2.00		8.03
	1.71	1.95		7.95
	1.72	1.91		7.87
	1.73	1.86		7.76
0.24	1.74	1.82		7.68
	1.75	1.78		7.60
	1.76	1.74		7.51
	1.77	1.70		7.43
0.25	1.78	1.66		7.33
	1.79	1.62		7.25
	1.80	1.58		7.18
	1.81	1.55		7.10
0.26	1.82	1.51		7.02
	1.83	1.48		6.93
	1.84	1.45		6.85
	1.85	1.42		6.78
	1.86	1.38		6.70
0.27	1.87	1.35		6.62
	1.88	1.32		6.55
	1.89	1.29		6.48
	1.90	1.26		6.40
0.28	1.91	1.23		6.33
	1.92	1.20		6.25
	1.93	1.17		6.18
	1.94	1.15		6.12
0.29	1.95	1.12		6.05
	1.96	1.10		5.98
	1.97	1.07		5.92
	1.98	1.05		5.85
	1.99	1.02		5.78
0.30	2.00	1.00		5.72
0.31	2.05	0.89		5.40
0.32	2.10	0.79		5.10
0.33	2.15	0.71		4.82
0.34	2.20	0.63		4.54

log *E*	*E*	Percentage Transmitted	90° Sector Angle	Polarizin Angle (45° extinction
0.35	2.25	0.56		4.28
0.36	2.30	0.50		4.05
0.37	2.35	0.45		3.82
0.38	2.40	0.40		3.62
0.39	2.45	0.36		3.42
0.40	2.50	0.32		3.22
0.41	2.55	0.28		3.05
	2.60	0.25		2.87
0.42	2.65	0.22		2.72
0.43	2.70	0.20		2.55
0.44	2.75	0.18		2.42
0.45	2.80	0.16		2.28
	2.85	0.14		2.15
0.46	2.90	0.13		2.03
0.47	2.95	0.11		1.92
0.48	3.00	0.10		1.82
	3.04	0.09		1.72
0.49	3.10	0.08		1.62
0.50	3.15	0.07		1.51
	3.20	0.06		1.43
0.51	3.25			1.36
0.52	3.30	0.05		1.28
	3.35			1.21
0.53	3.40	0.04		1.14
0.54	3.45			1.08
	3.50	0.03		1.02
0.55	3.55			0.97
	3.60			0.91
0.56	3.65			0.86
0.57	3.70	0.02		0.81
	3.75			0.76
0.58	3.80			0.72
	3.85			0.68
0.59	3.90	0.01		0.64
	3.95			0.60
0.60	4.00			
0.65	4.50			
0.70	5.00			
0.74	5.50			
0.78	6.00			
0.81	6.50			
0.85	7.00			
0.88	7.50			
0.90	8.00			
0.93	8.50			
0.95	9.00			
0.98	9.50			
1.00	10.00			
∞	∞			

SPECTRUM CHARTS

The following plates (Plates II to XXXVI) are of the iron spectrum from 2310 to 5090 A with identified iron lines and indicated position of the principal lines of other elements.

The blank space above the iron spectrum is intended for use as a projection screen or for the superposition of an enlarged strip of the unknown spectrum and adjacent iron comparison spectrum. The vertical lines in this blank space are extended lines for a few of the unknown elements so as to permit vertical alignment of the projected spectrum lines.

In order to fill the pages a different reduction was used on some of these plates as compared with others. This change in reduction size is particularly noticeable between the series of Plates II to XXVII and the series of Plates XXVIII to XXXVI.

Note: Wavelength and intensity values in these charts are based on data given in Kayser's "Hauptlinien" **(1926) (A55).**

PLATE II

2310–2335

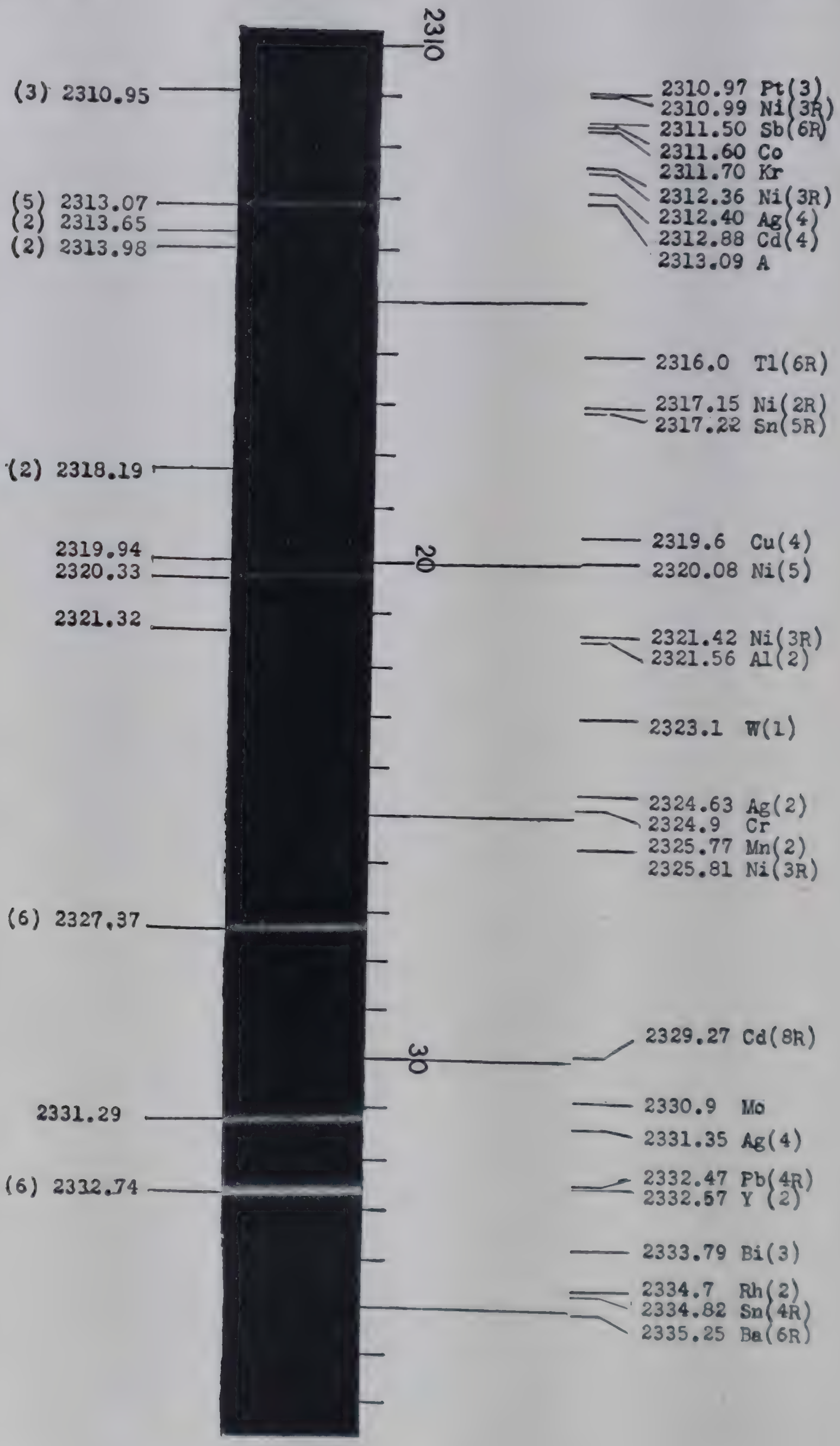


PLATE III

2330–2360 A

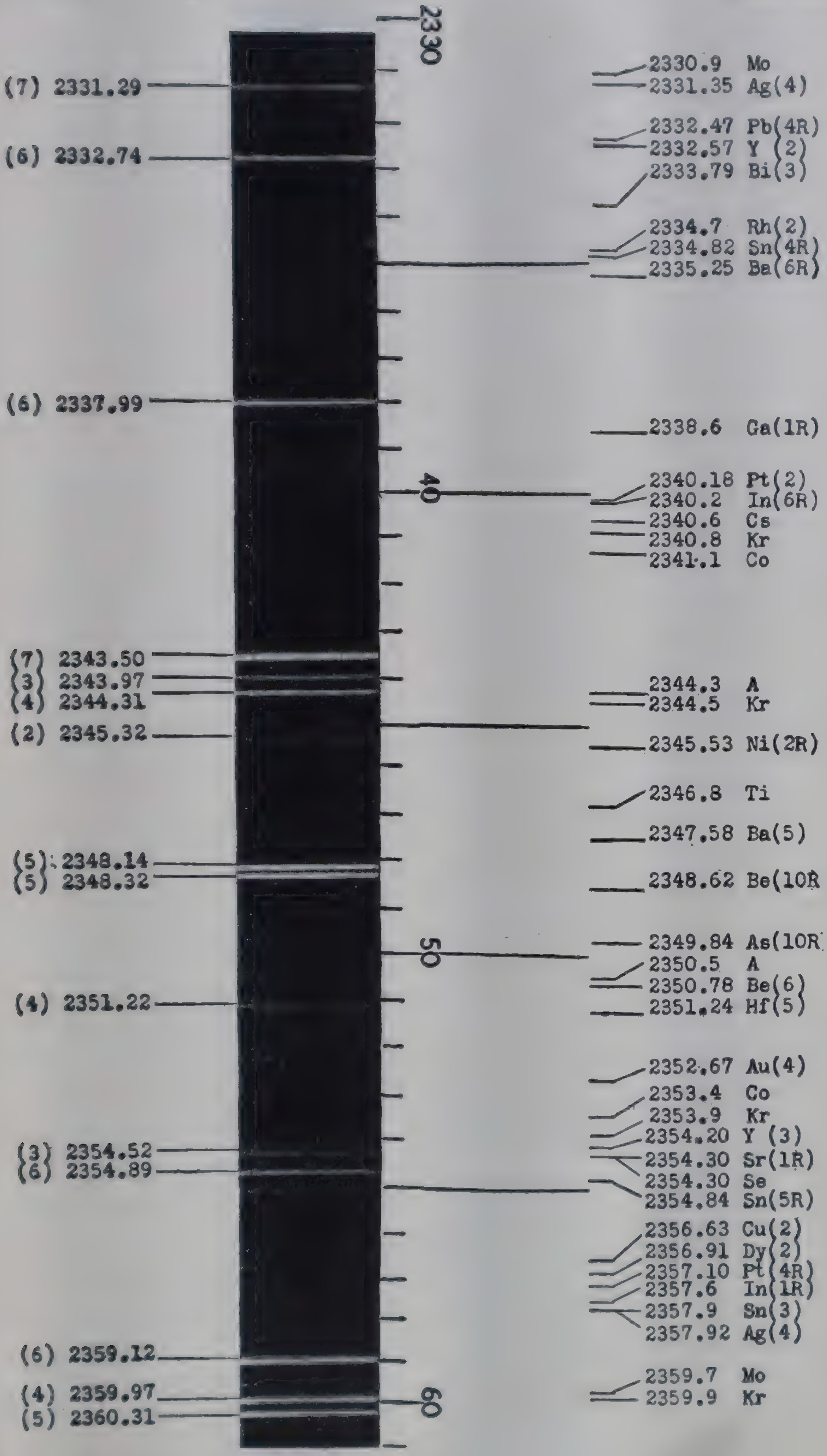


PLATE IV

2360–2390

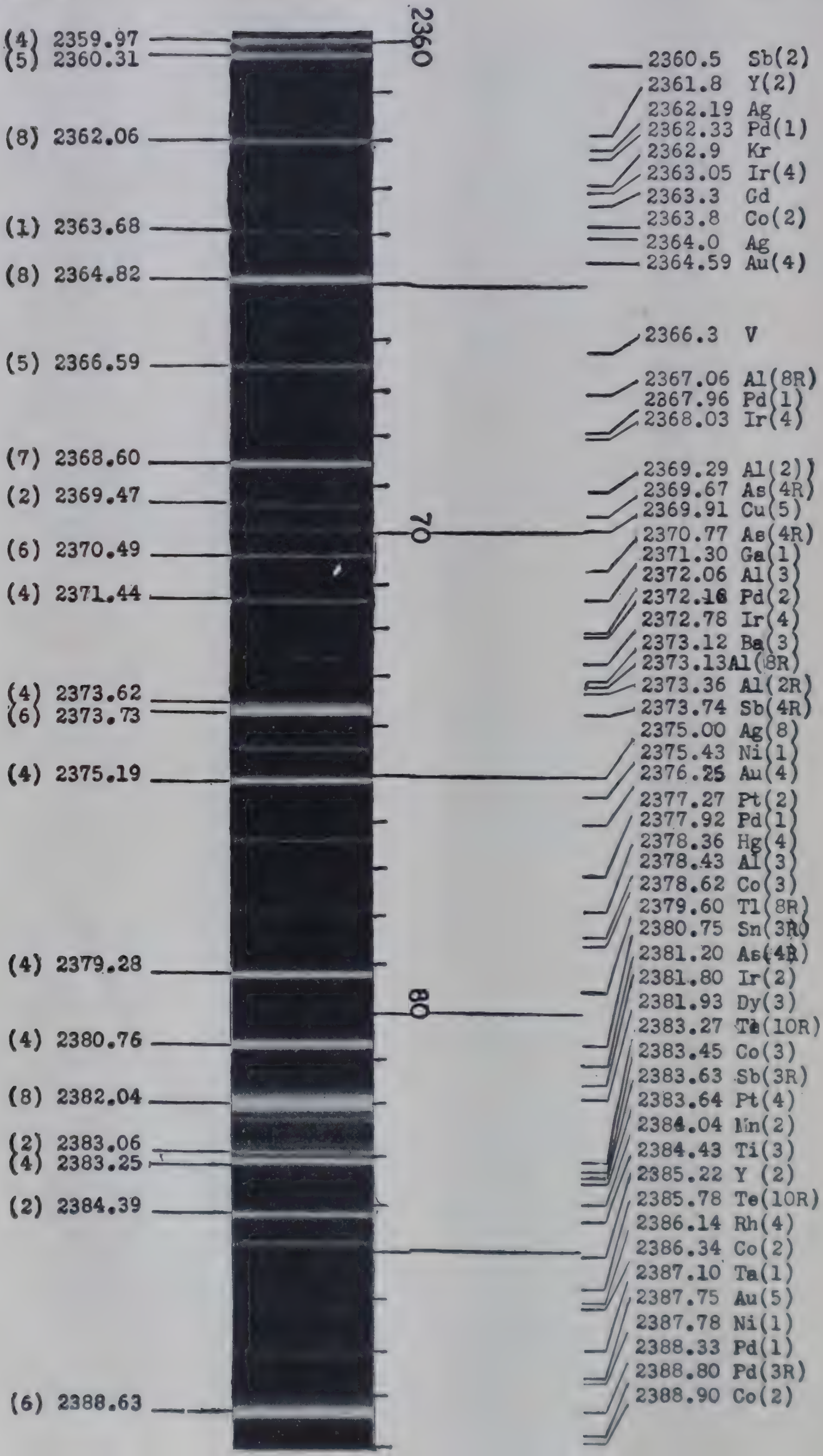


PLATE V

2390-2420 A

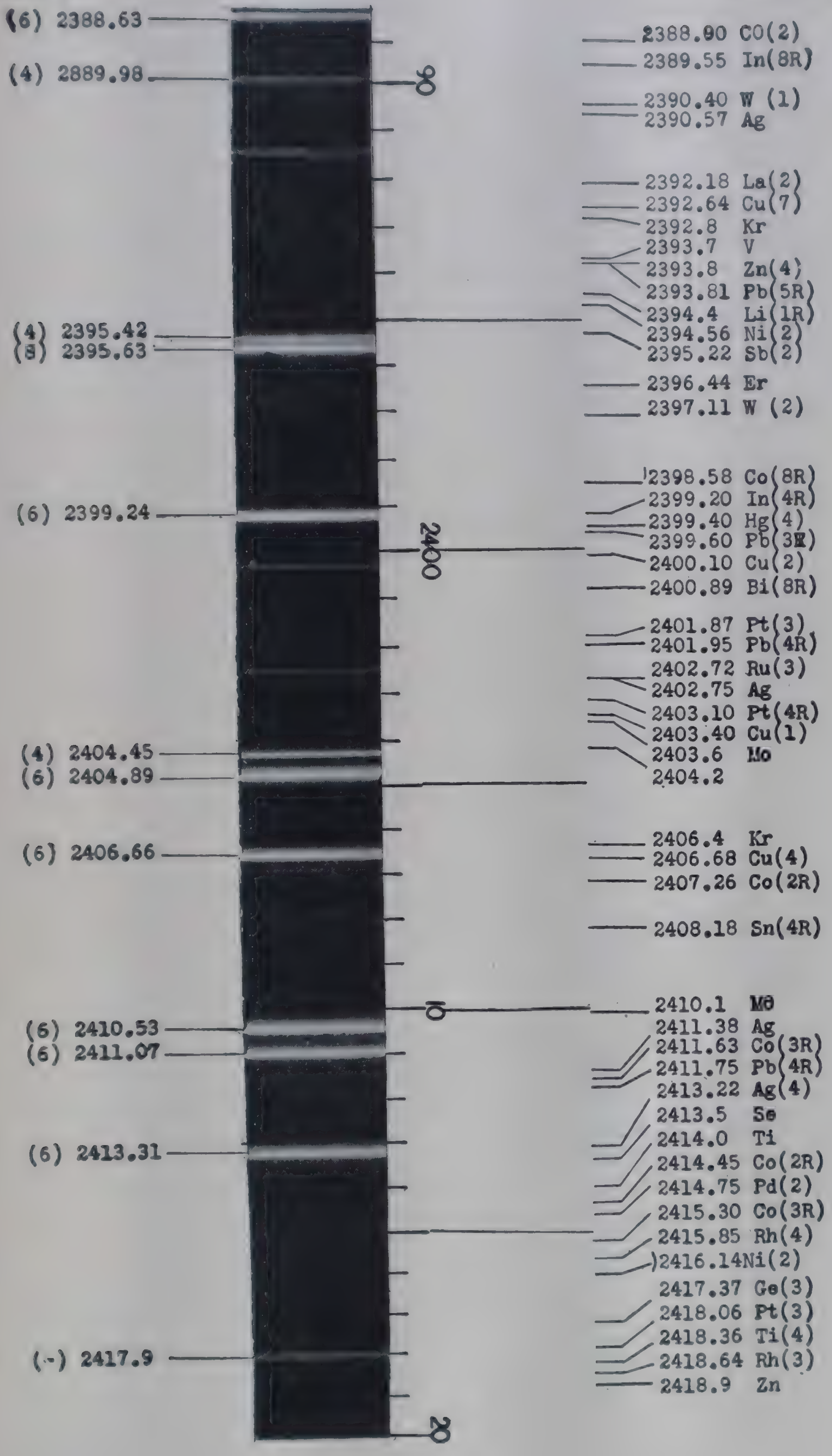


PLATE VI

2417–2452 A

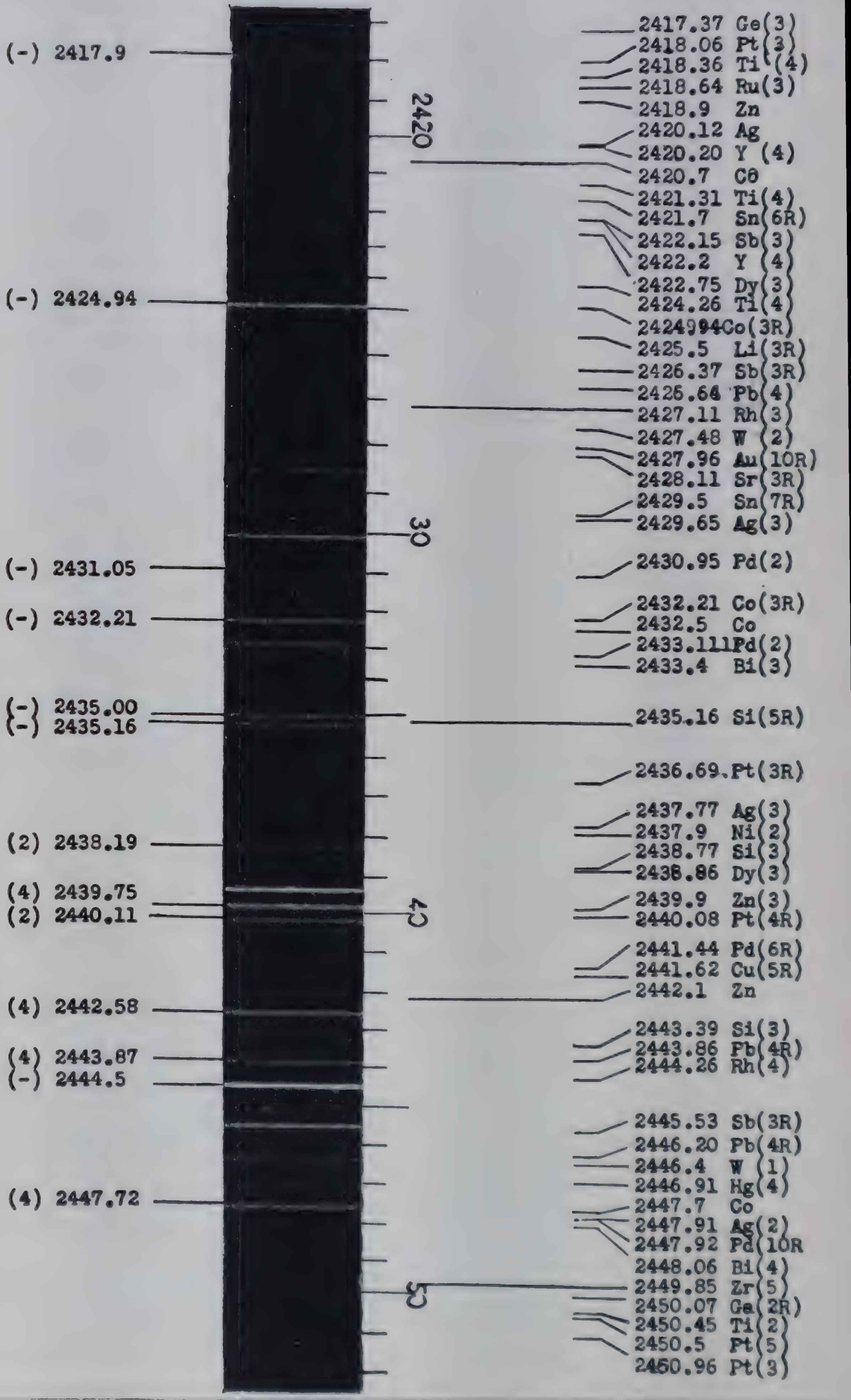


PLATE VII

2452–2487 A

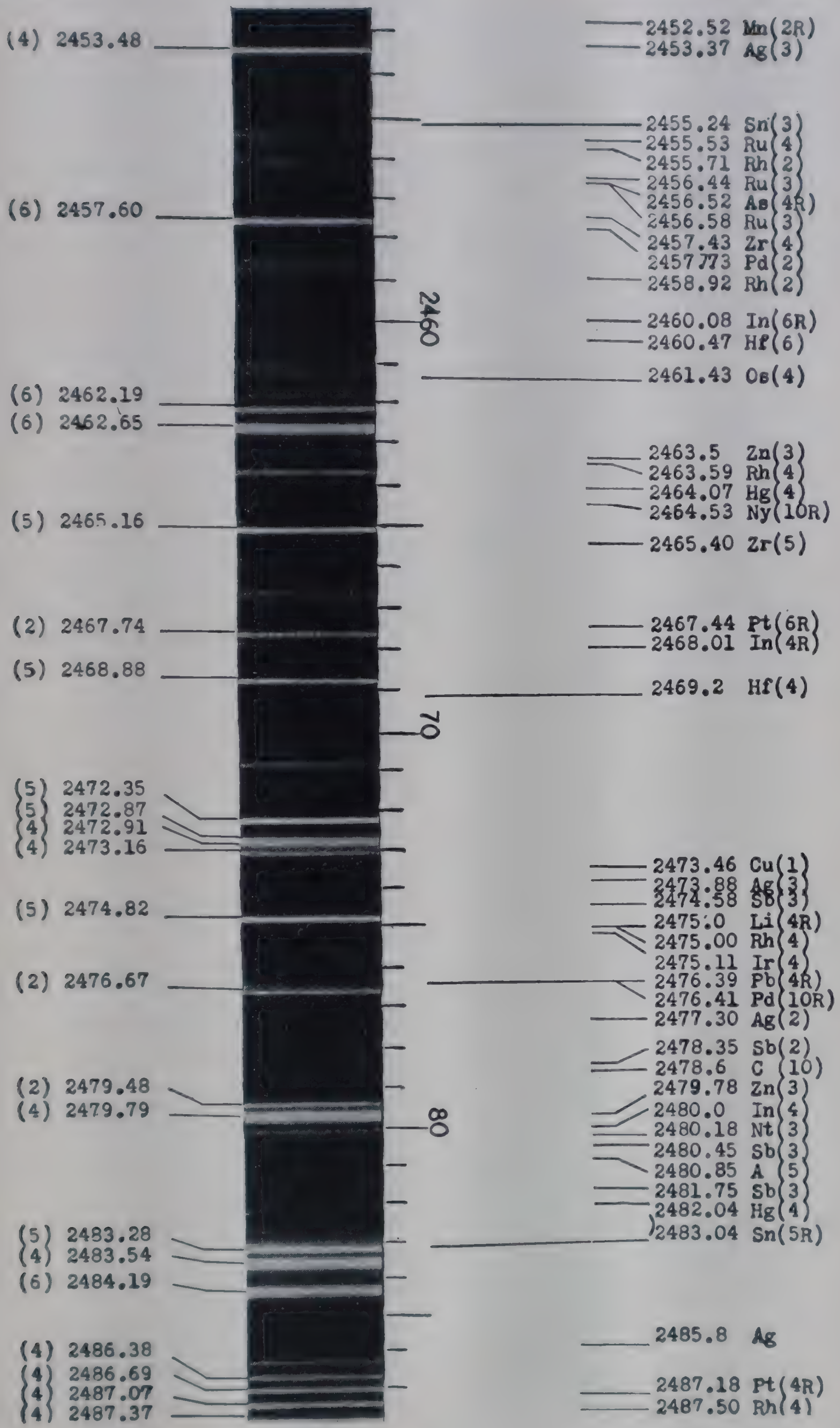


PLATE VIII

2487–2520 A

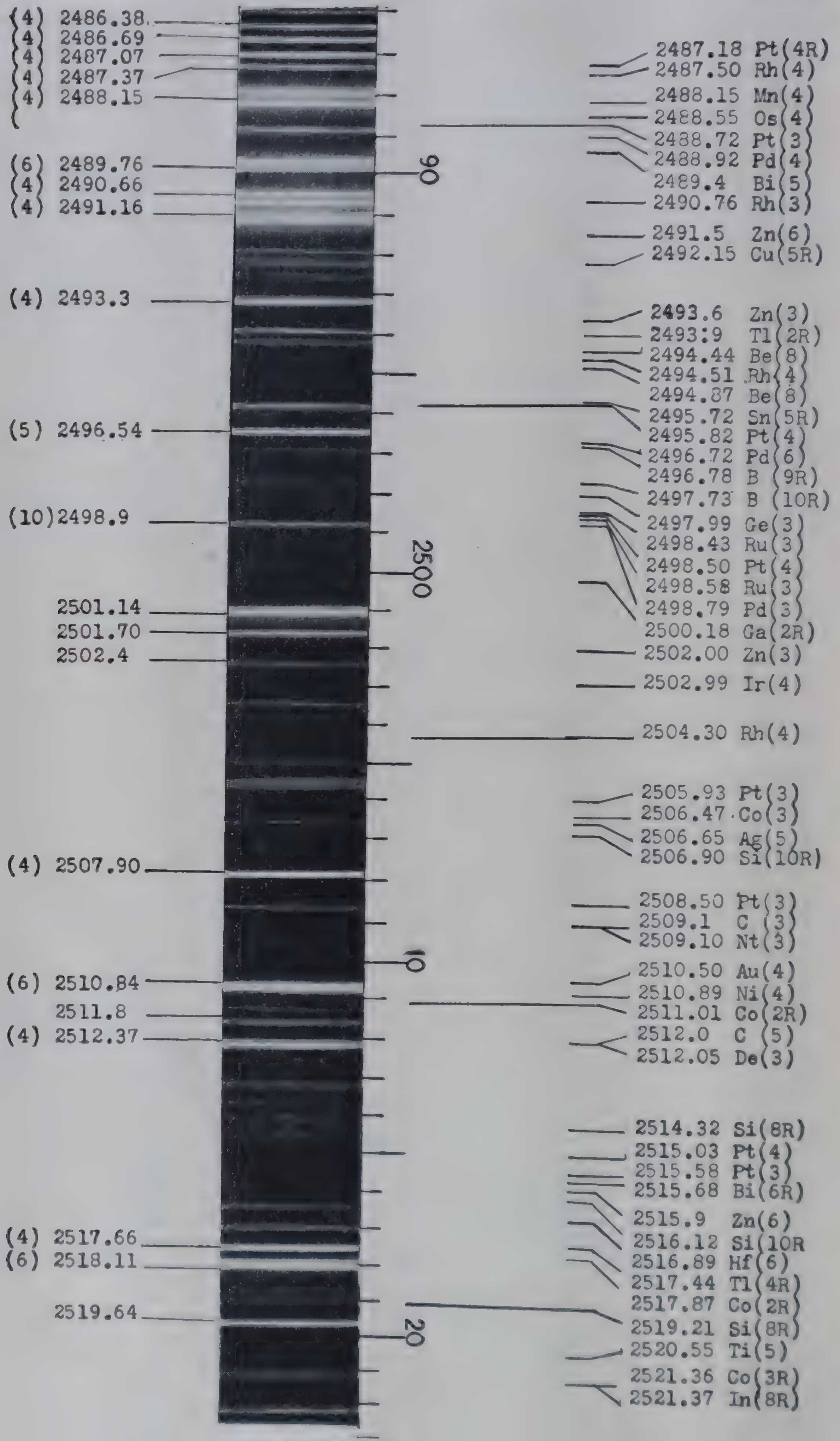


PLATE IX

2520–2555 A

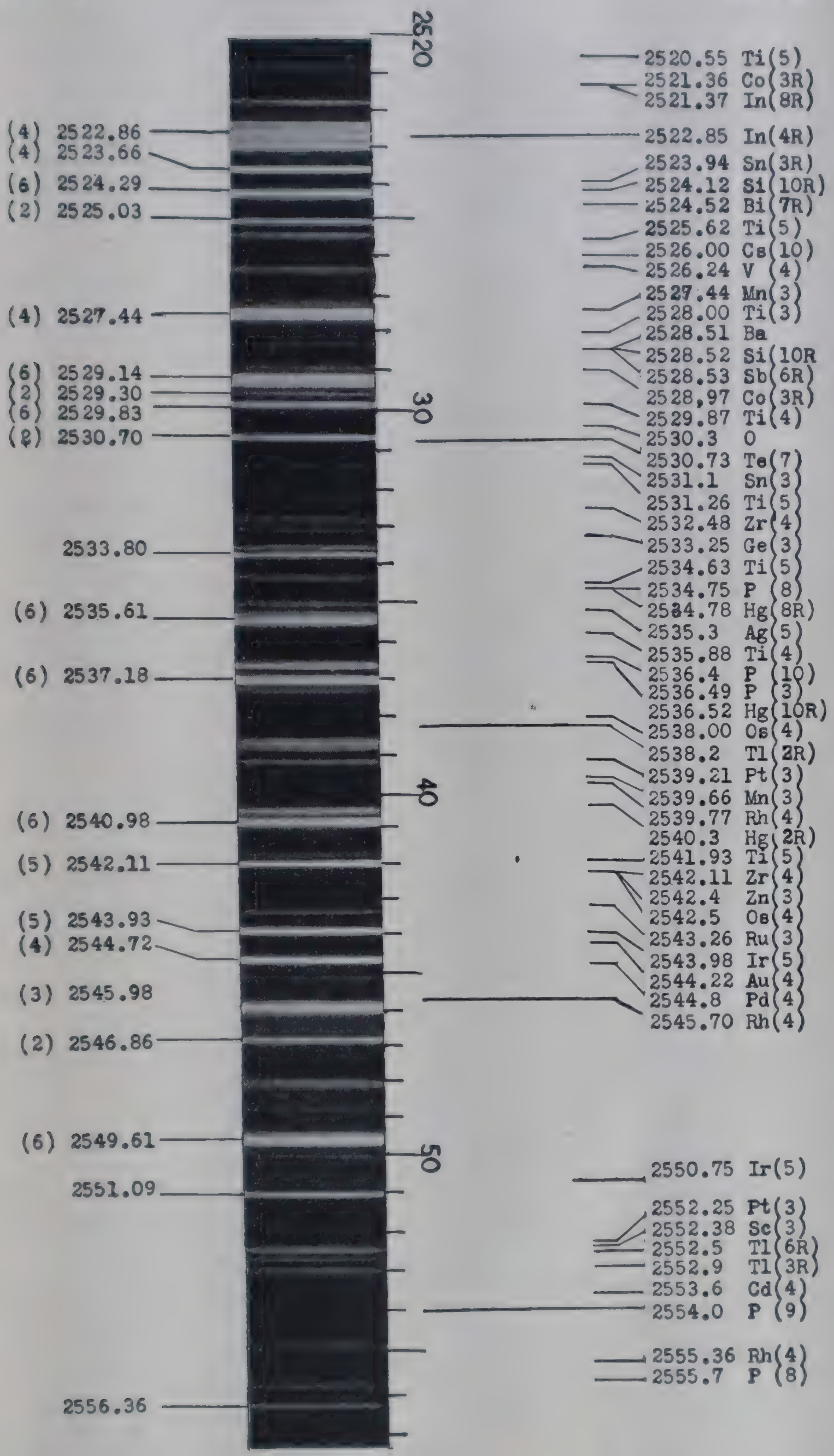


PLATE X

2555–2590

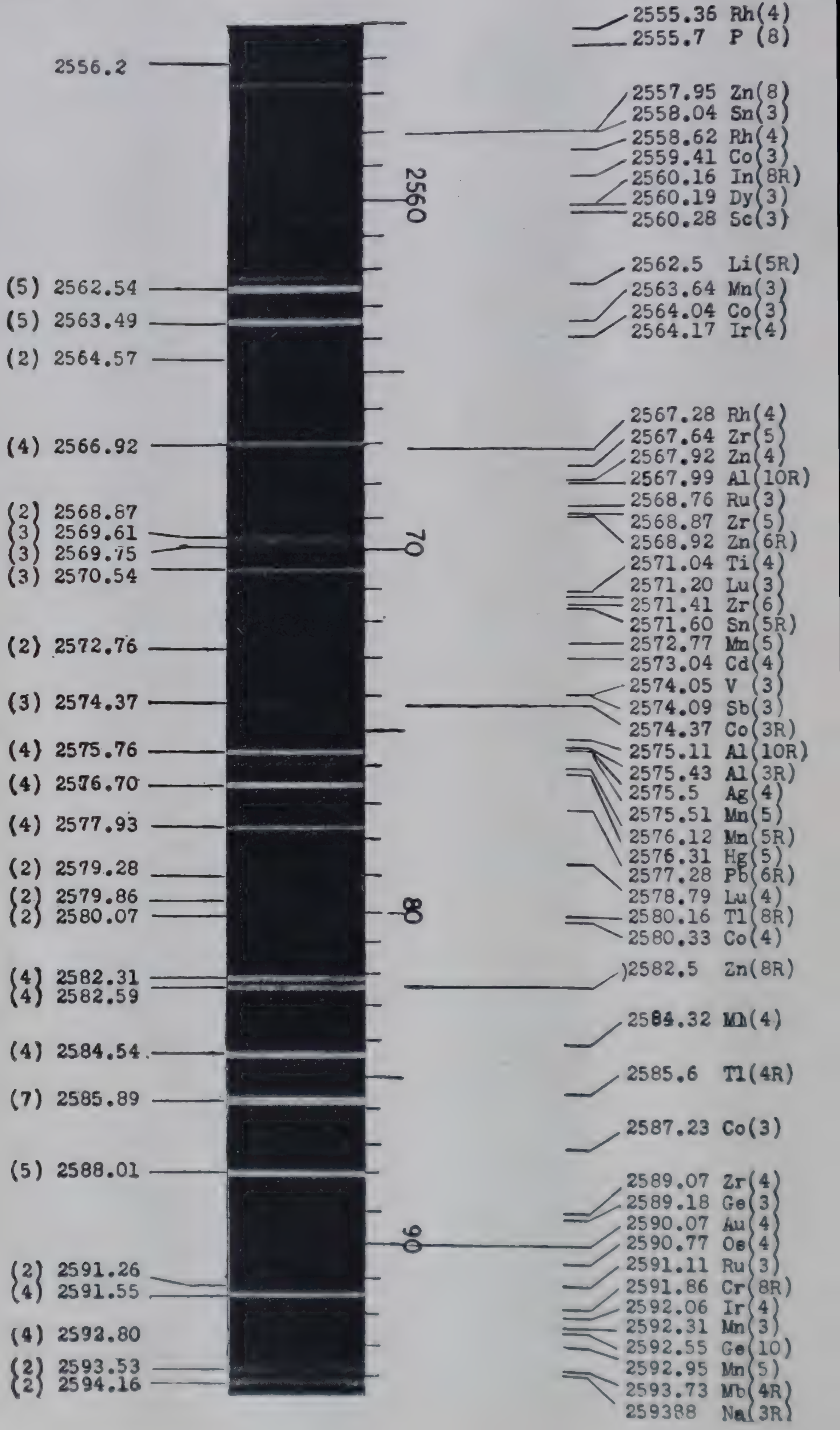


PLATE XI

2590–2630 A

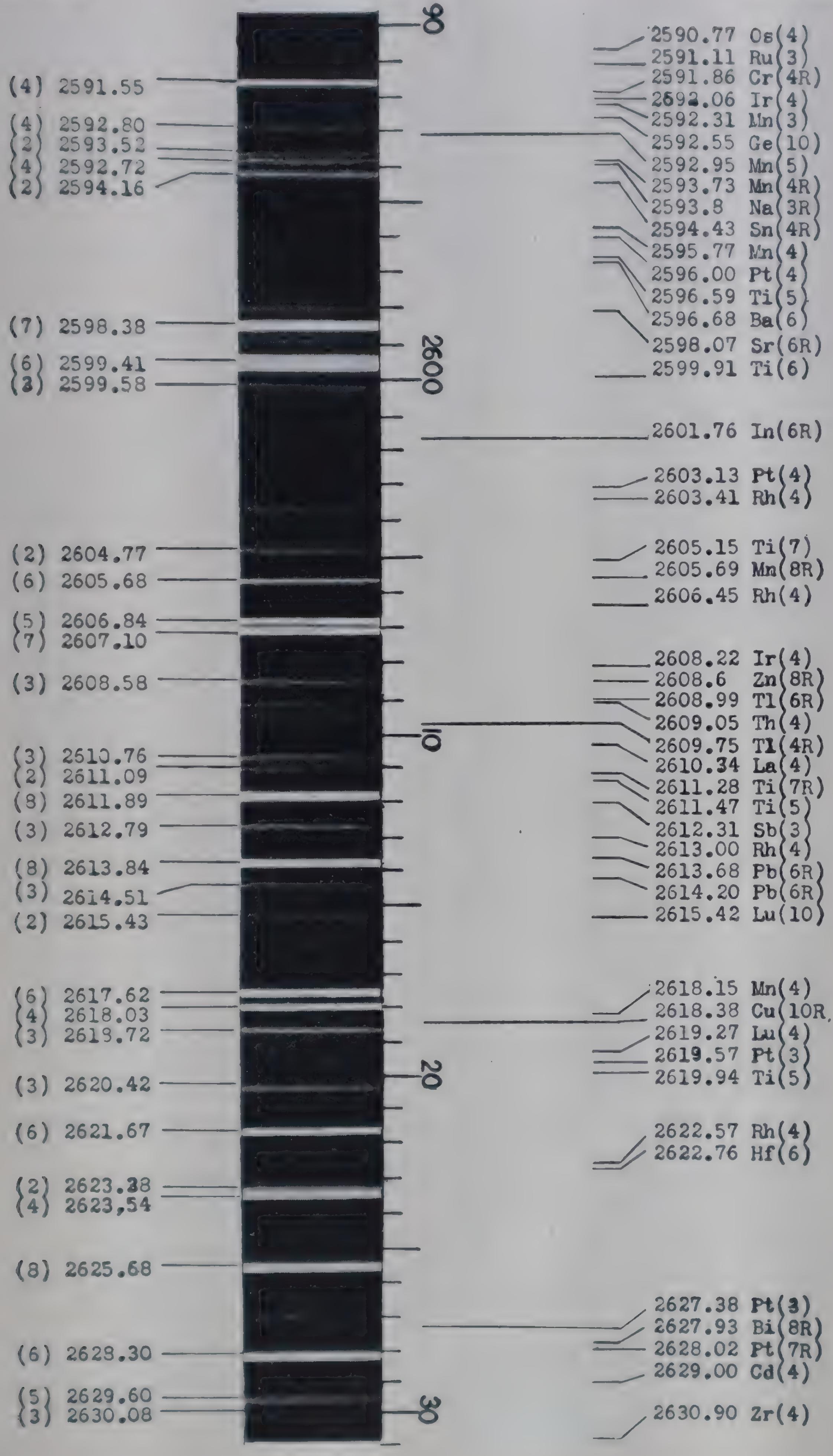


PLATE XIV

2630-2668 A

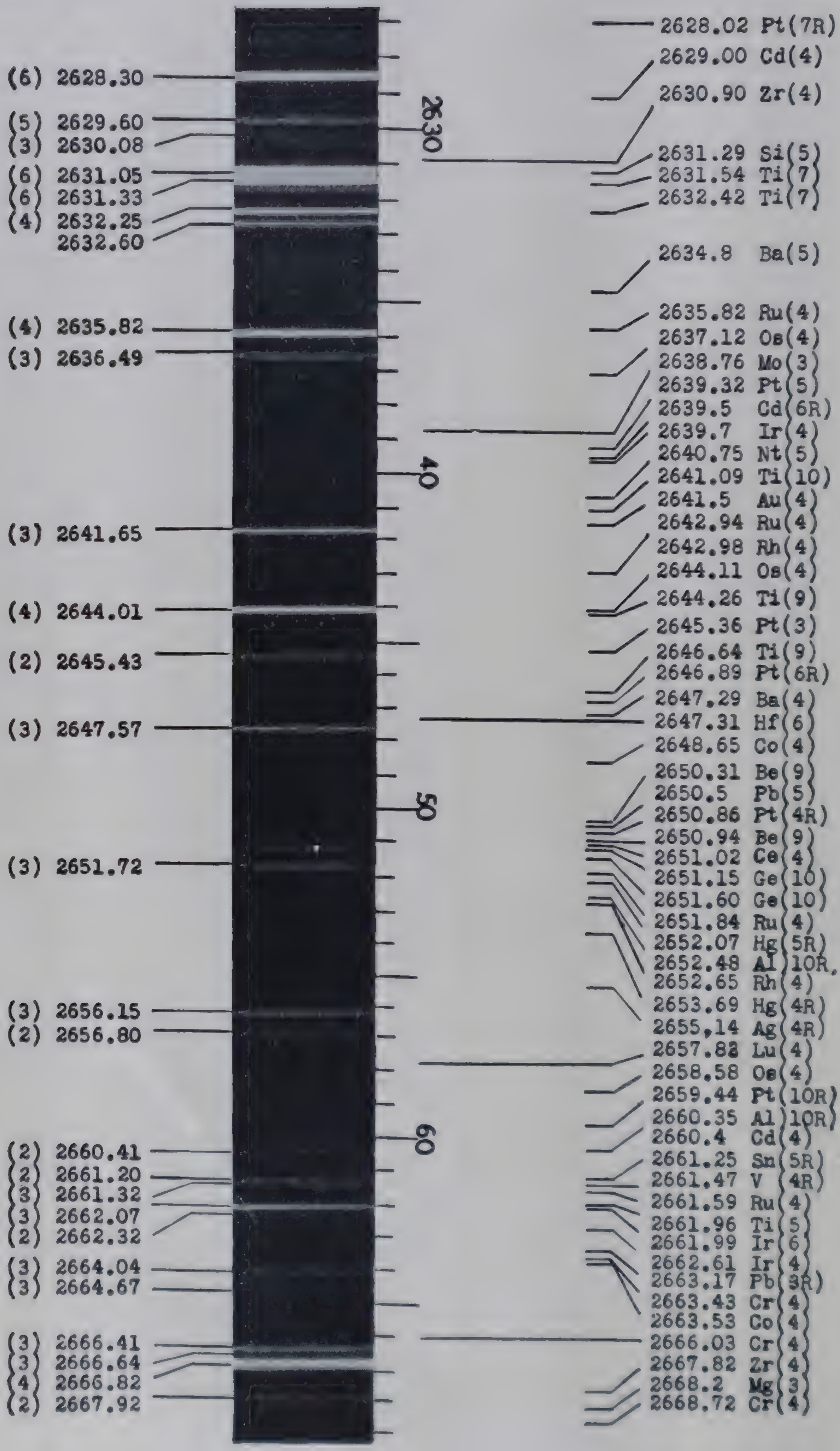


PLATE XIII

2668–2712 A

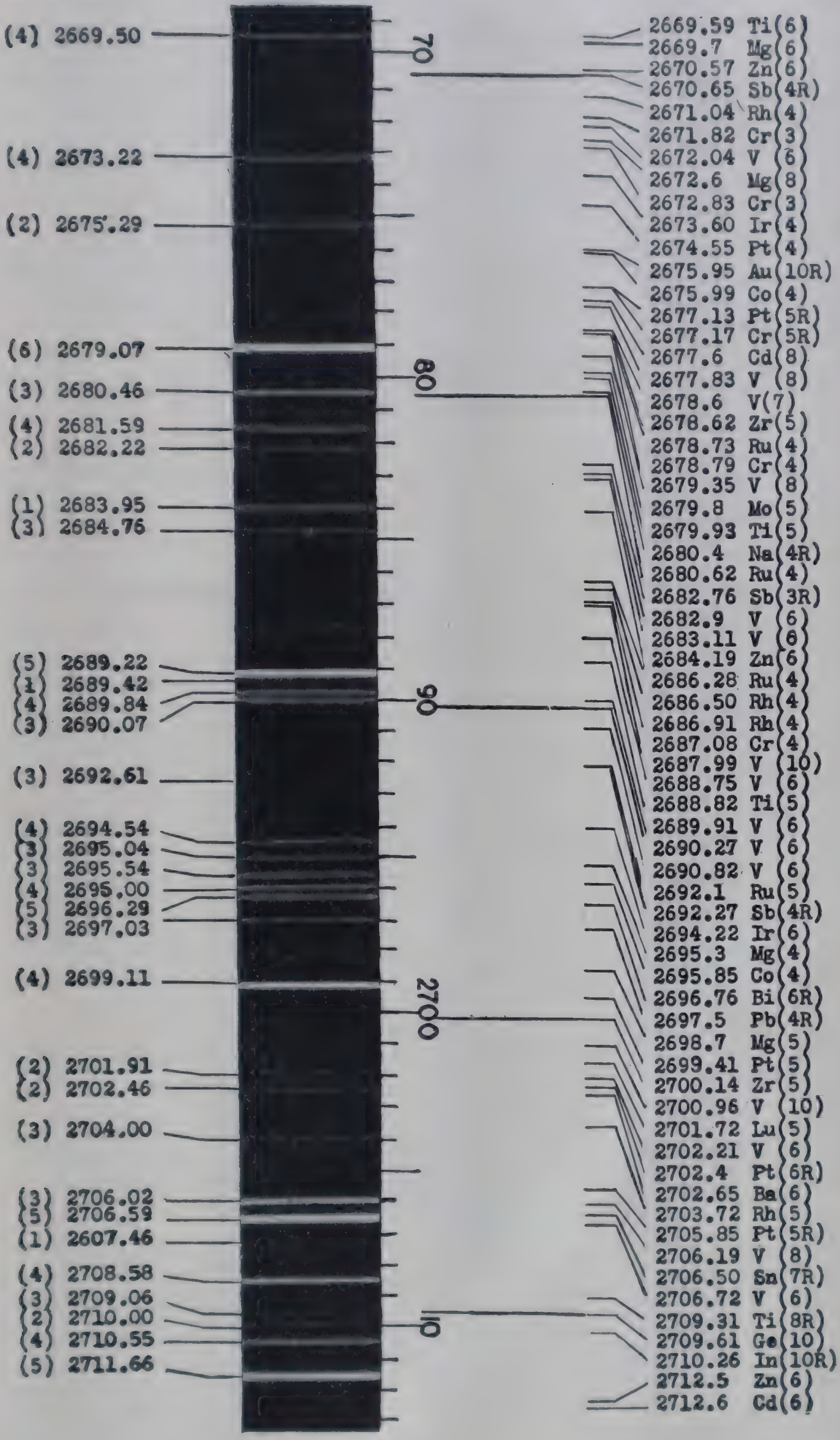


PLATE XIV 2712–2758A

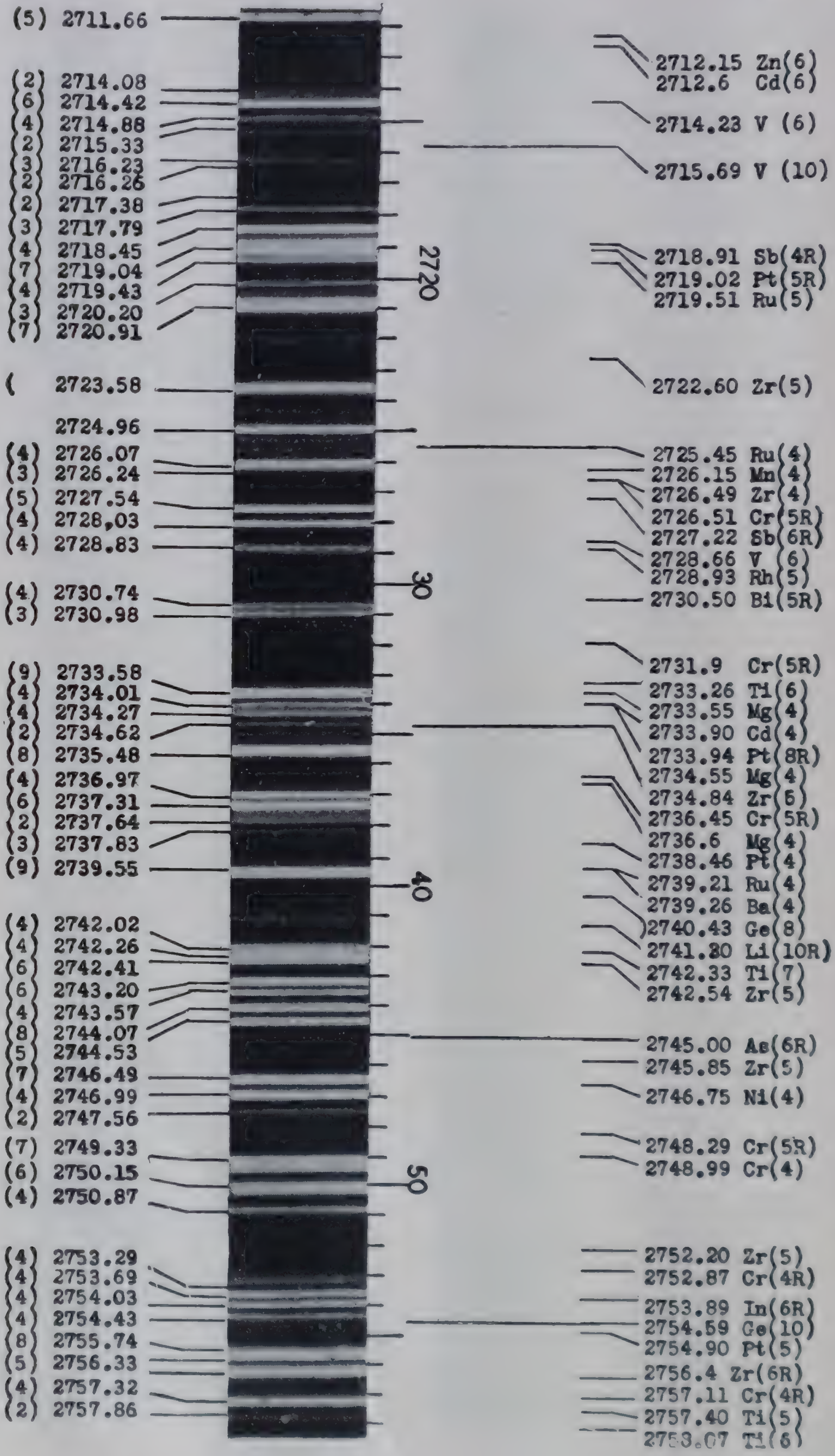


PLATE XXI

3060–3134 A

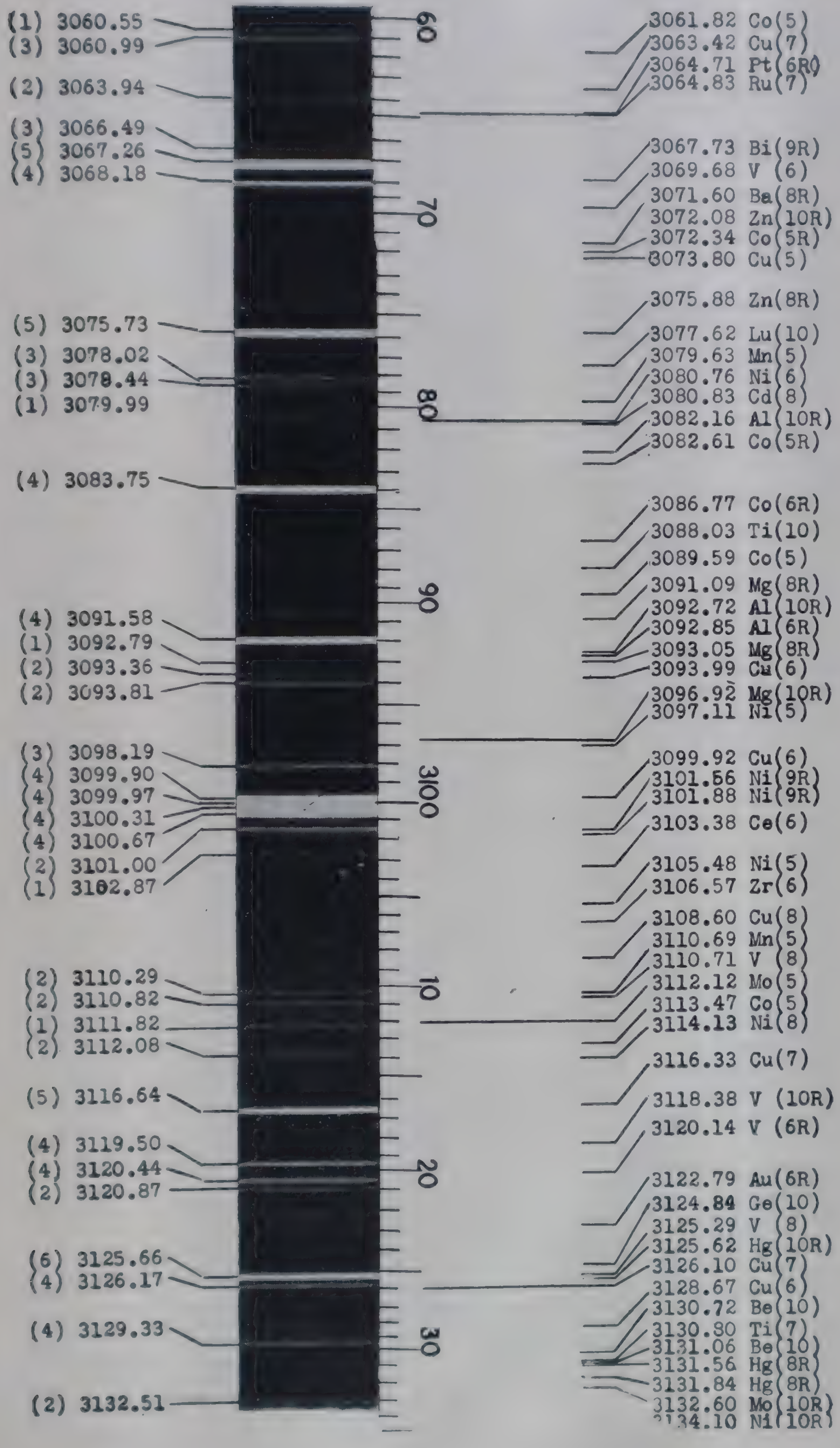


PLATE XXII

3130–3203

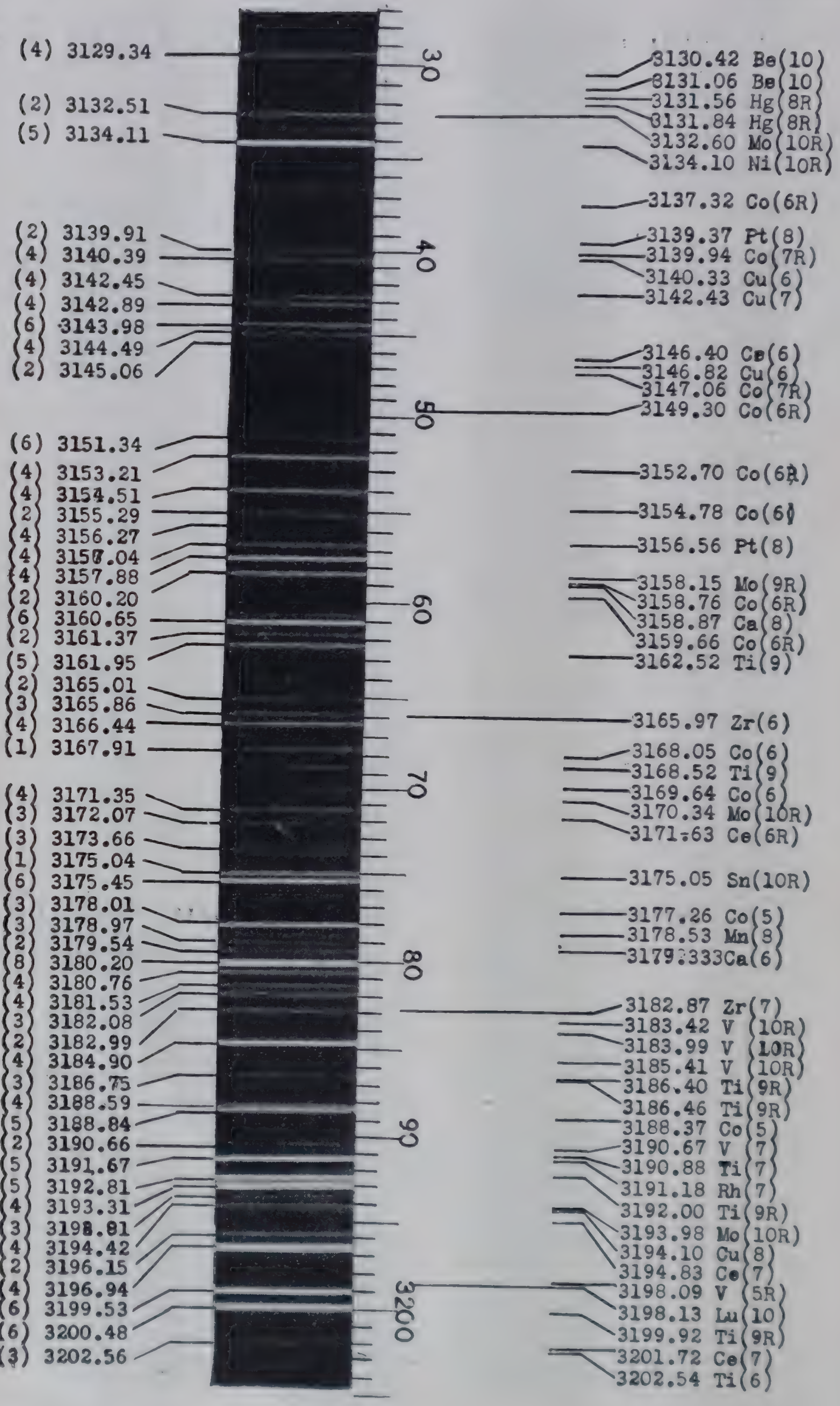


PLATE XXIII

3205–3283 A

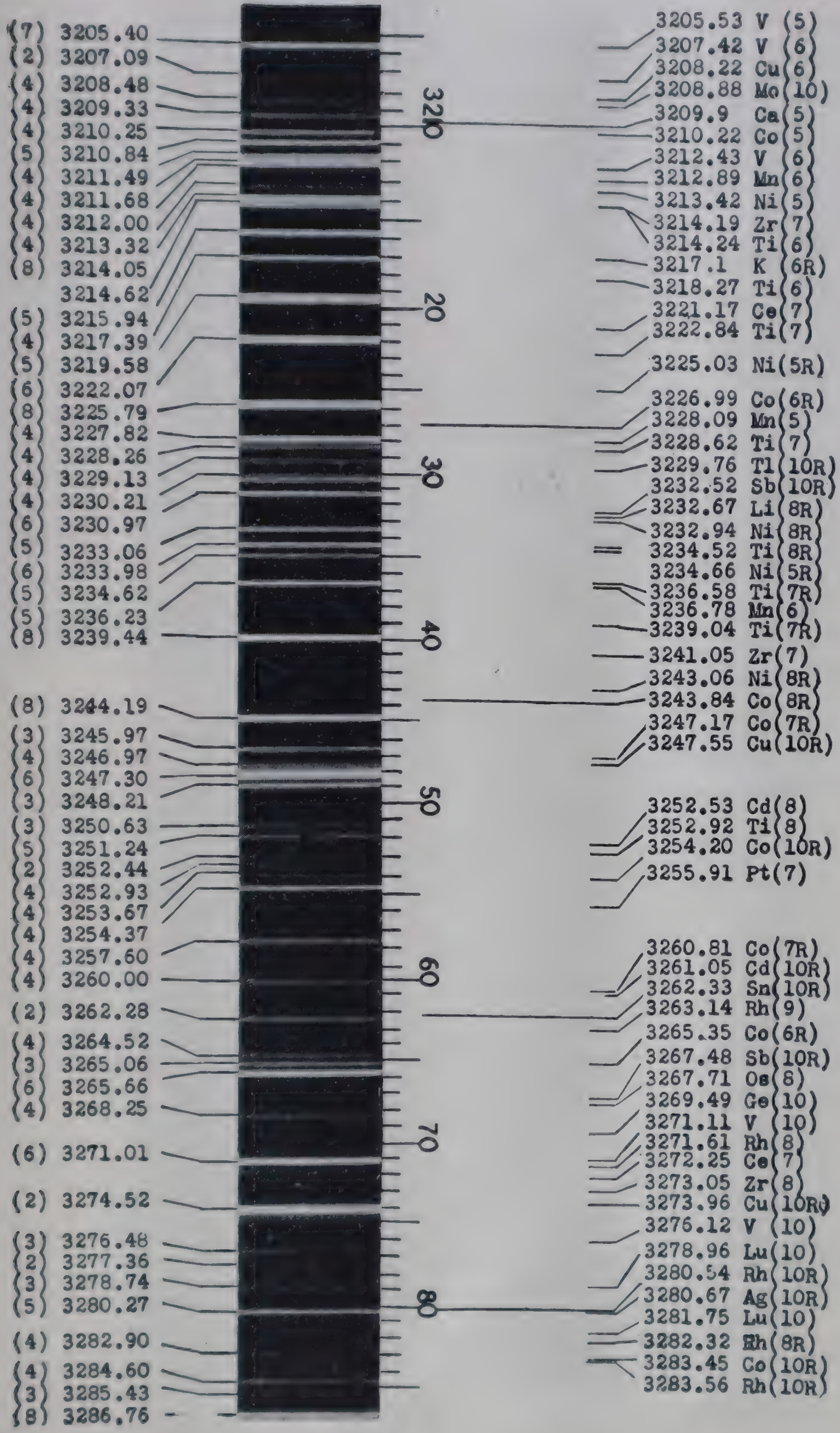


PLATE XXIV

3217–3305 A

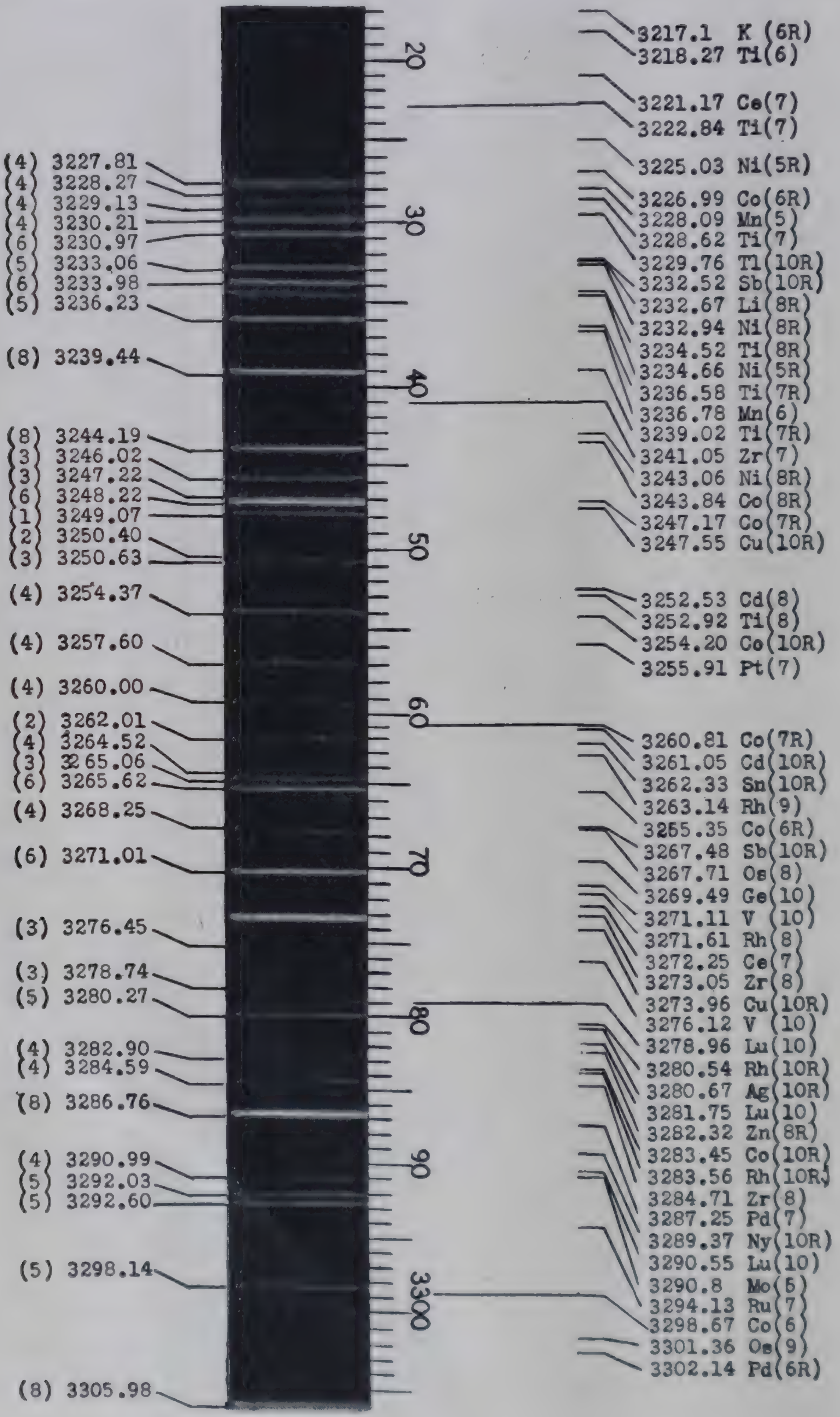


PLATE XXV

3300–3397 A

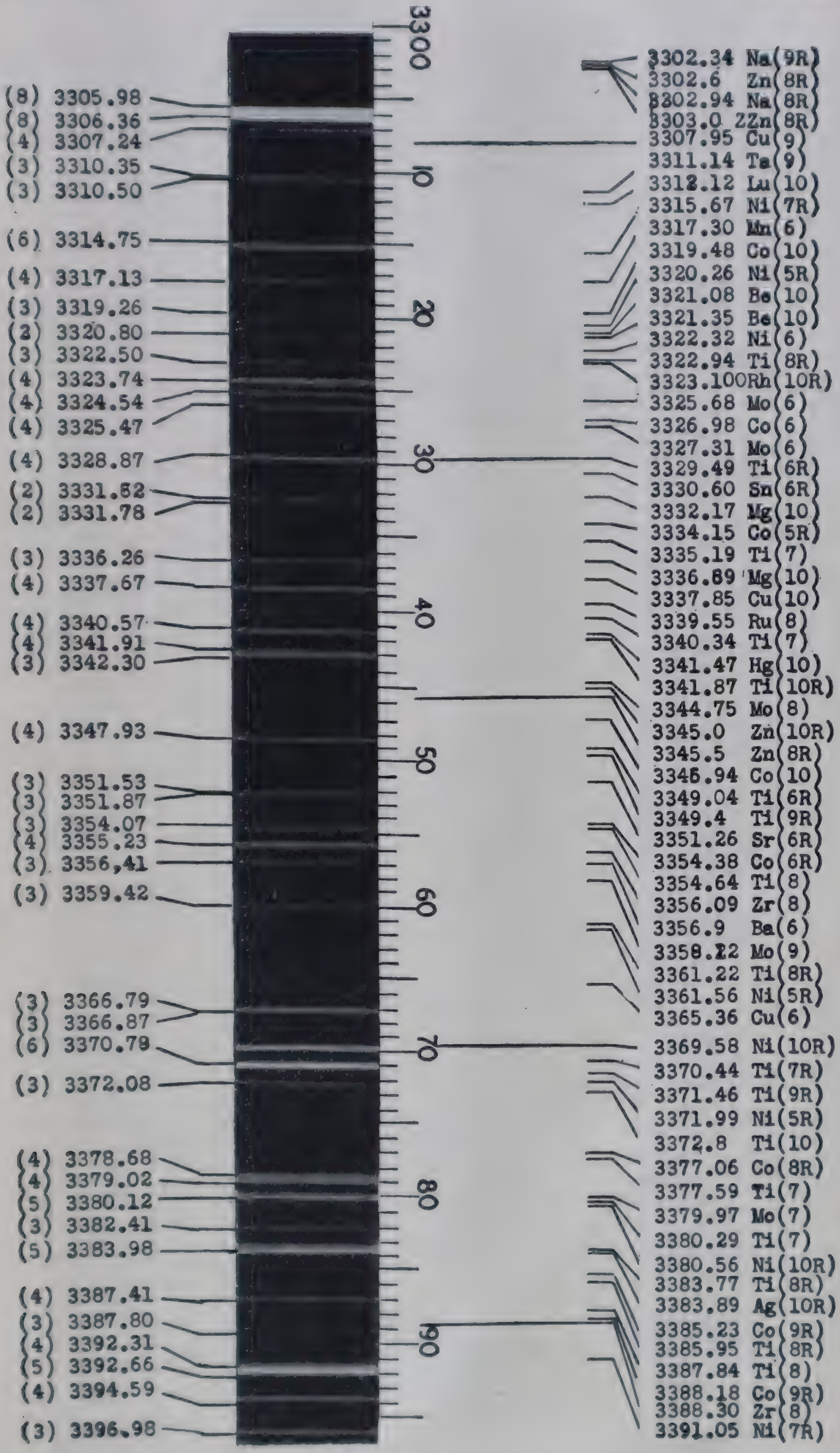


PLATE XXVI

3390-3495 A

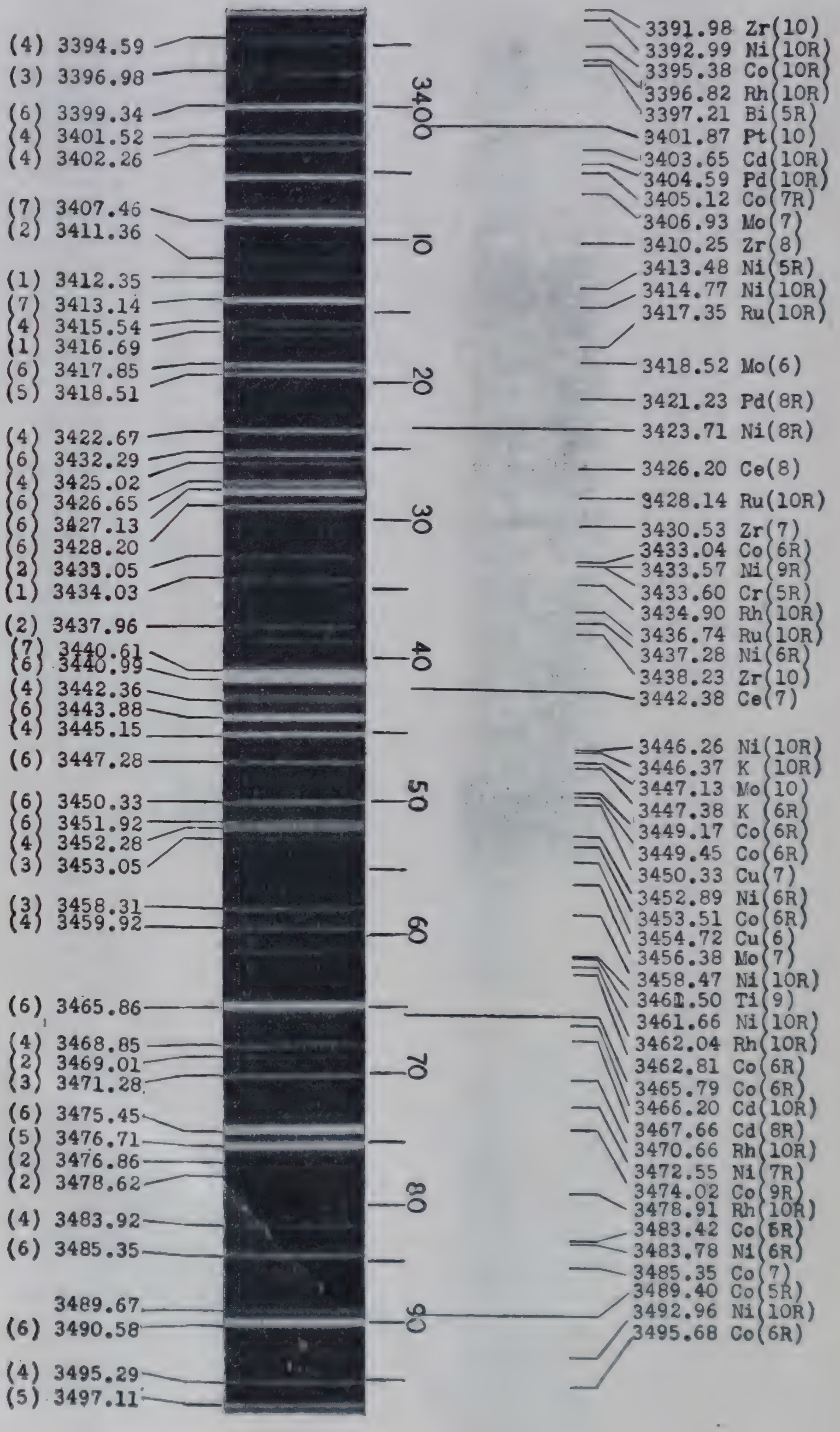


PLATE XXVII

3485–3595 A

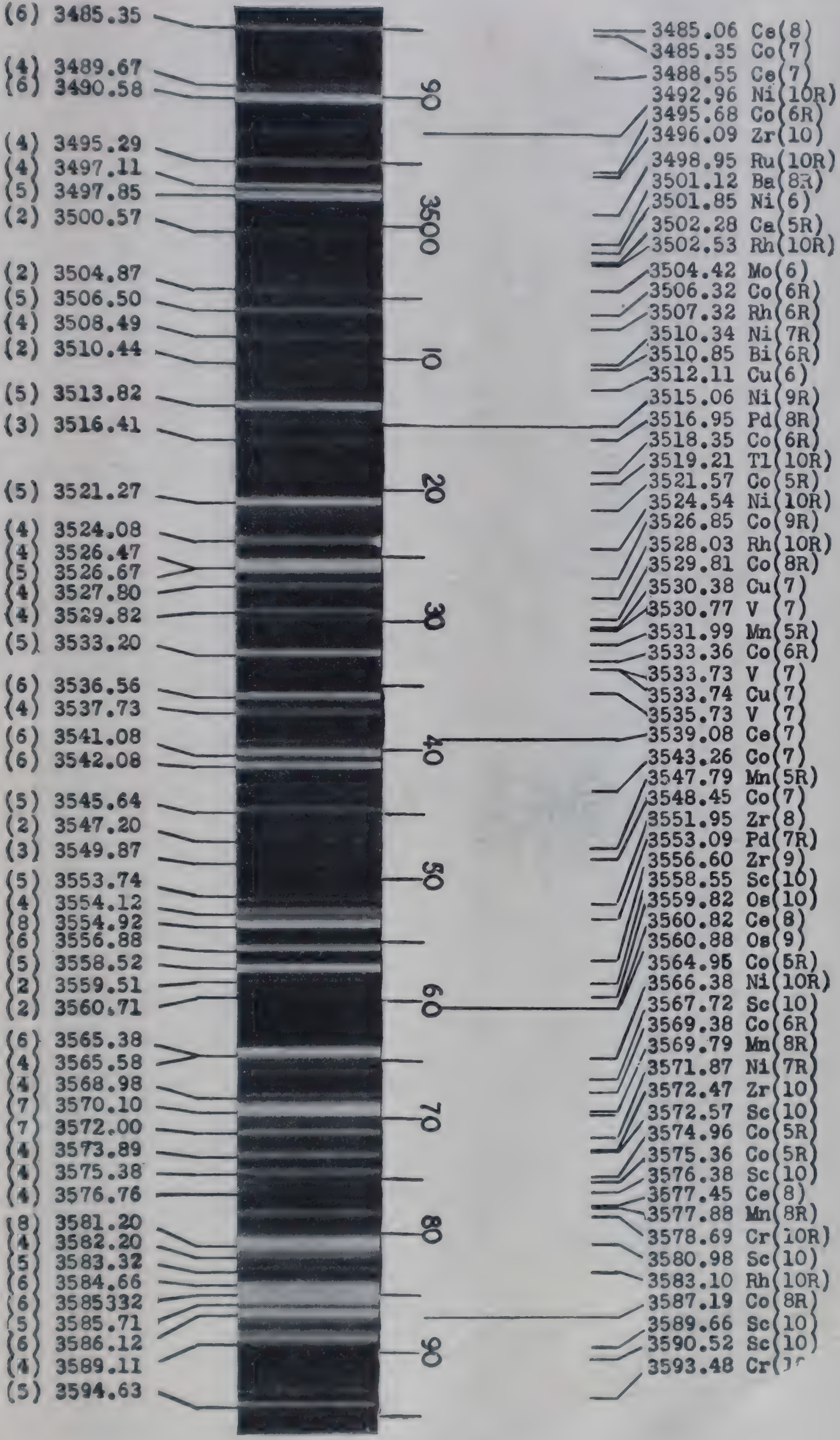
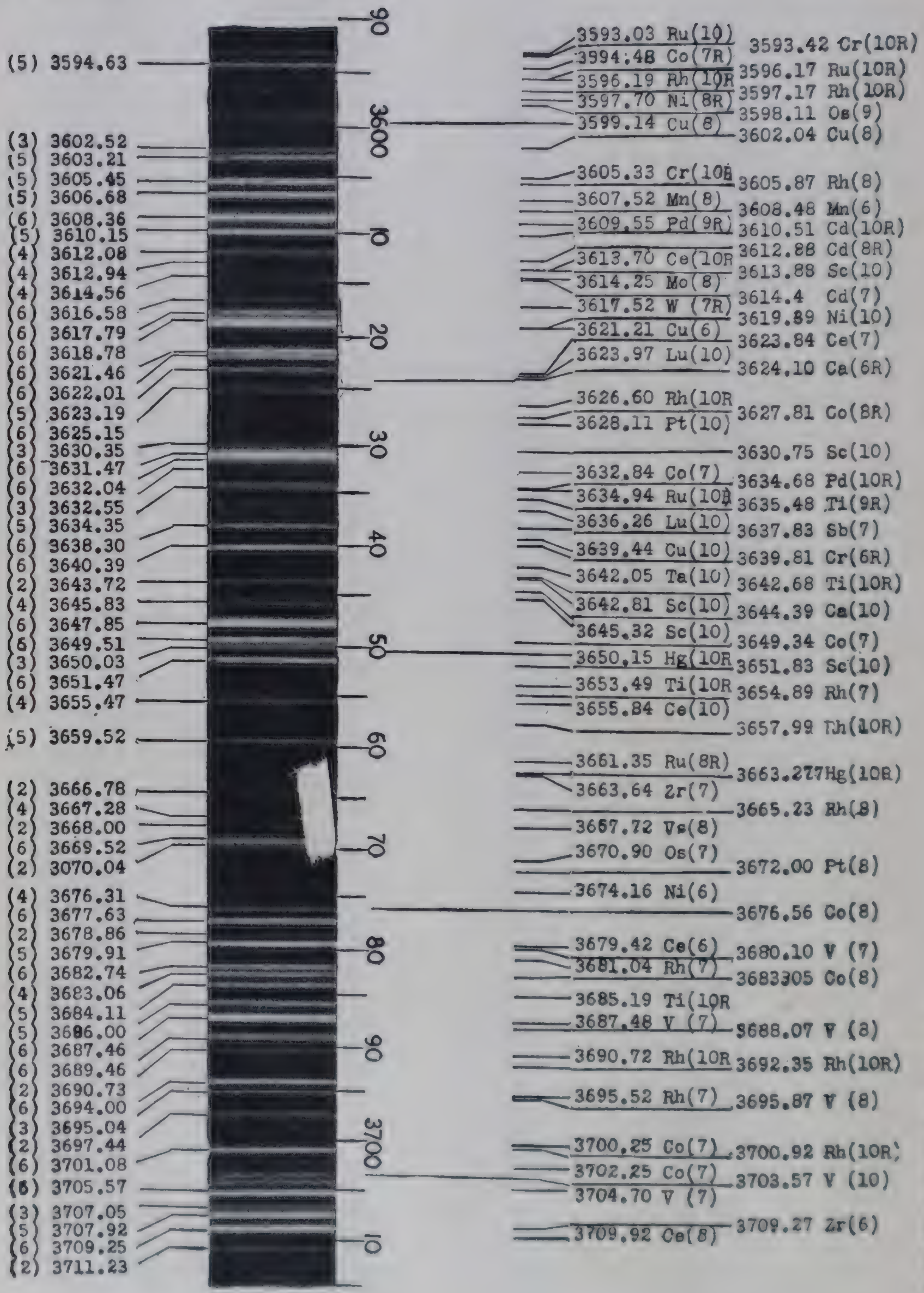


PLATE XXVIII

3595–3710 A



(5)

PLATE XXIX 3705–3834 A

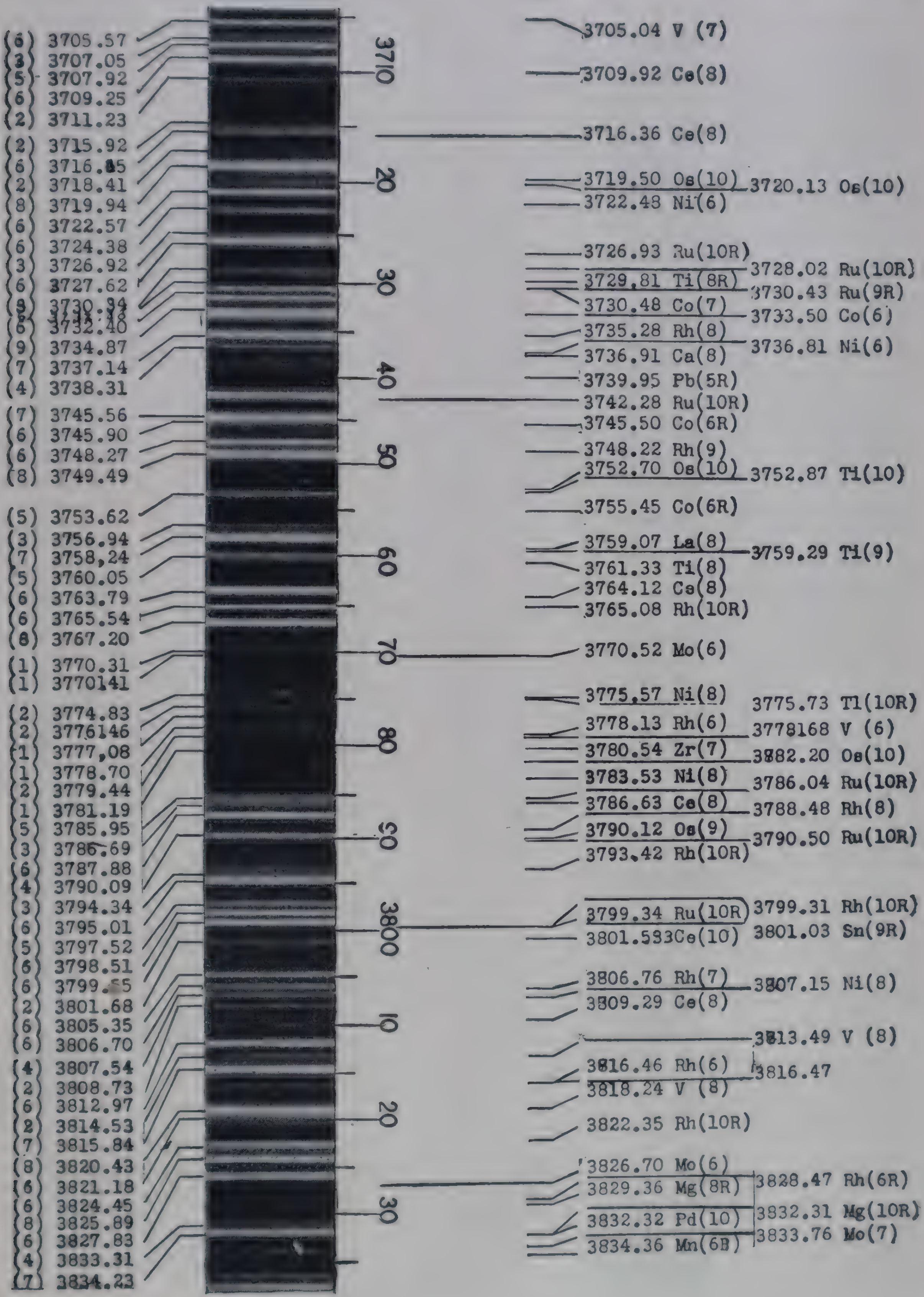


PLATE XXX

3820–3960 A

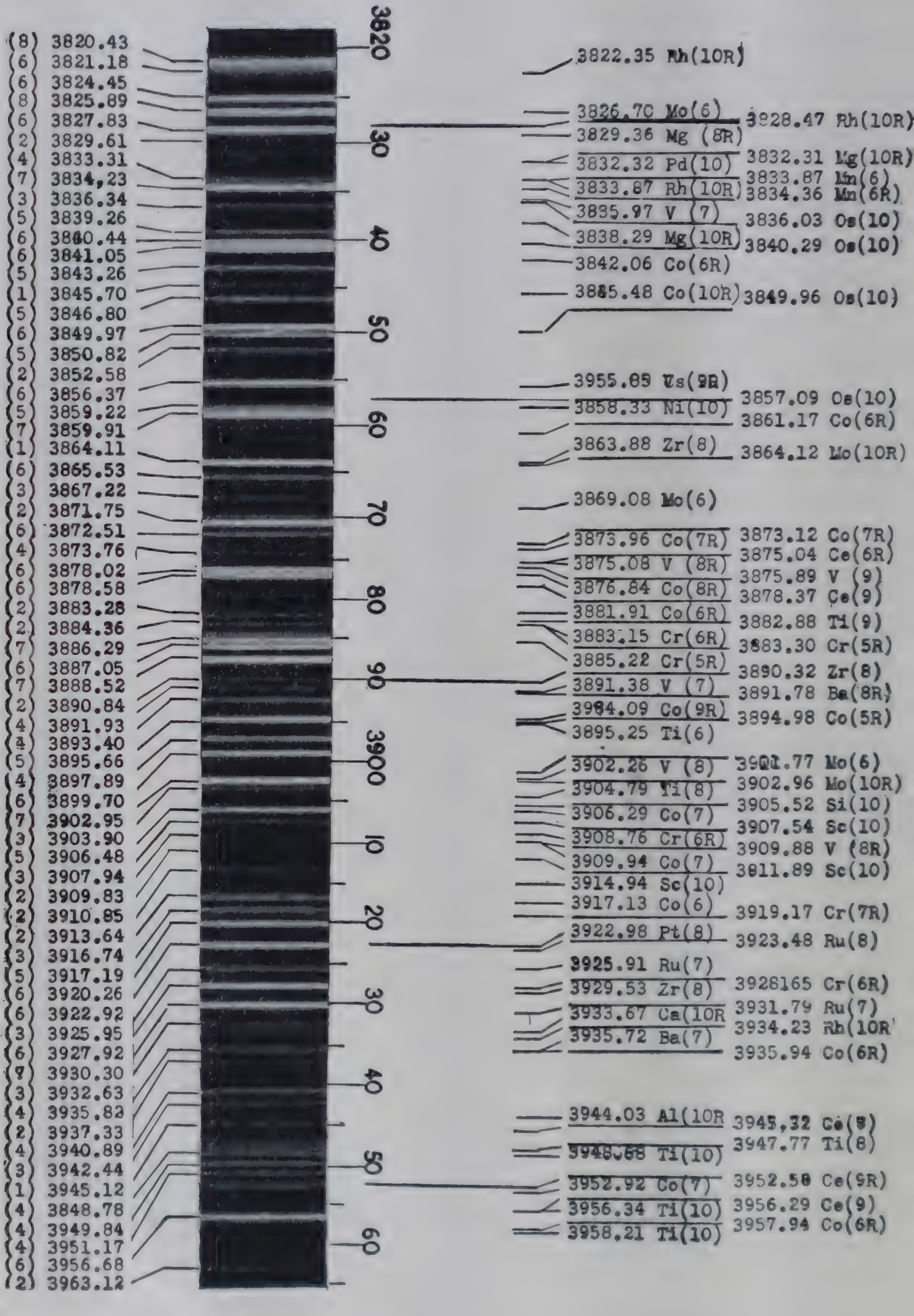


PLATE XXXI

3950–4100 A

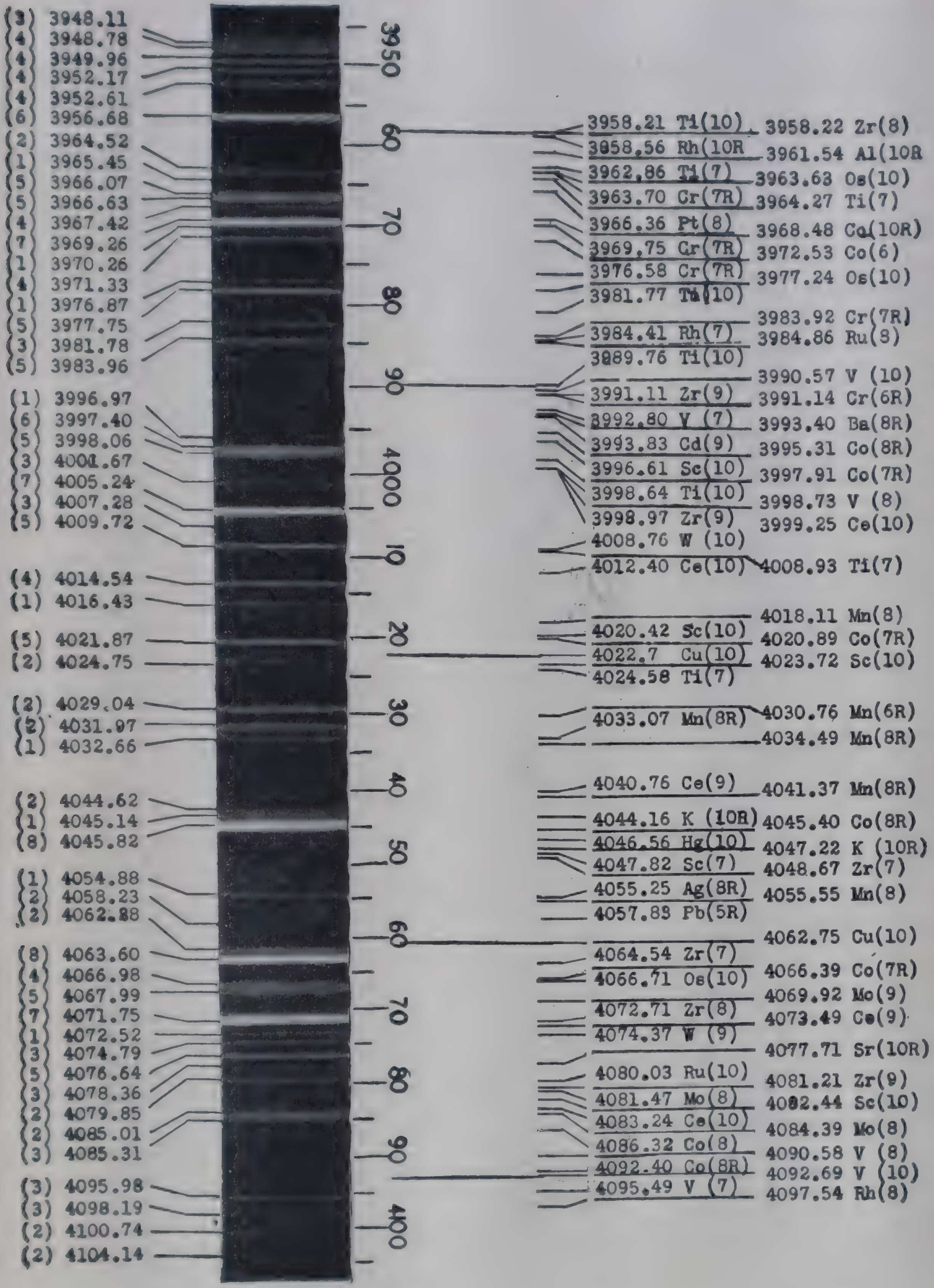


PLATE XXXII 4100–4270 A

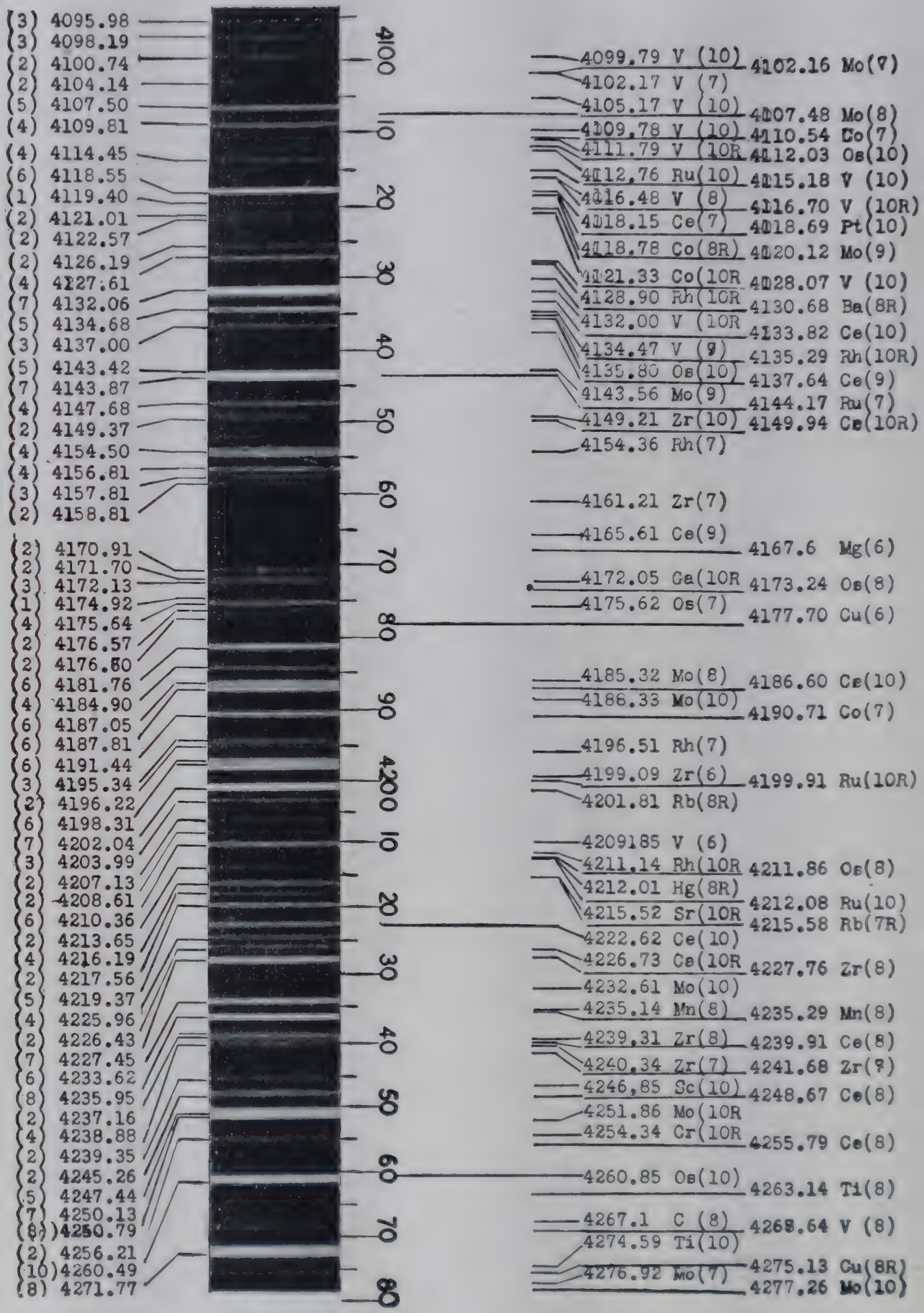


PLATE XXXIII

4200–4400 A

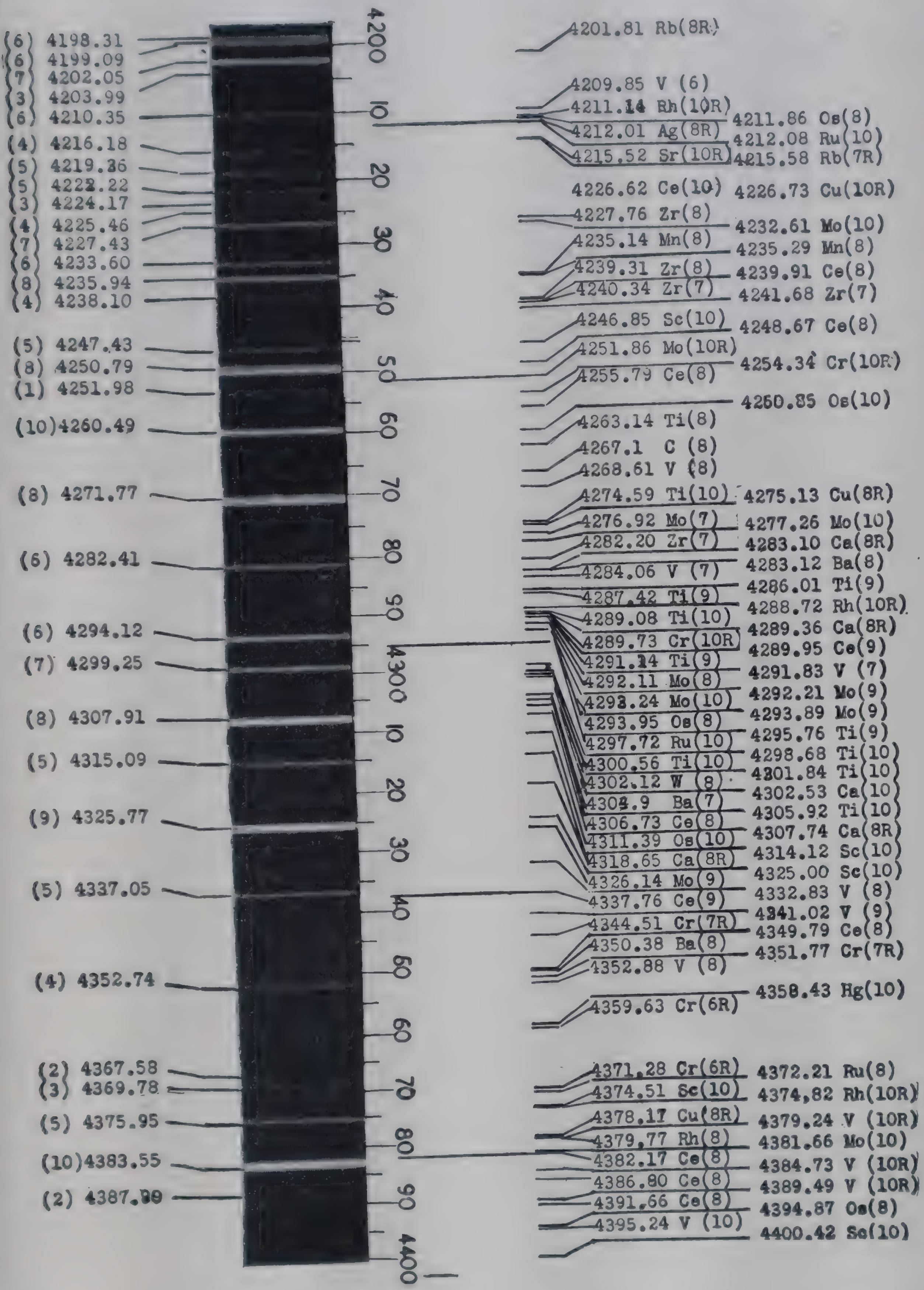


PLATE XXXIV

4400–4630 A

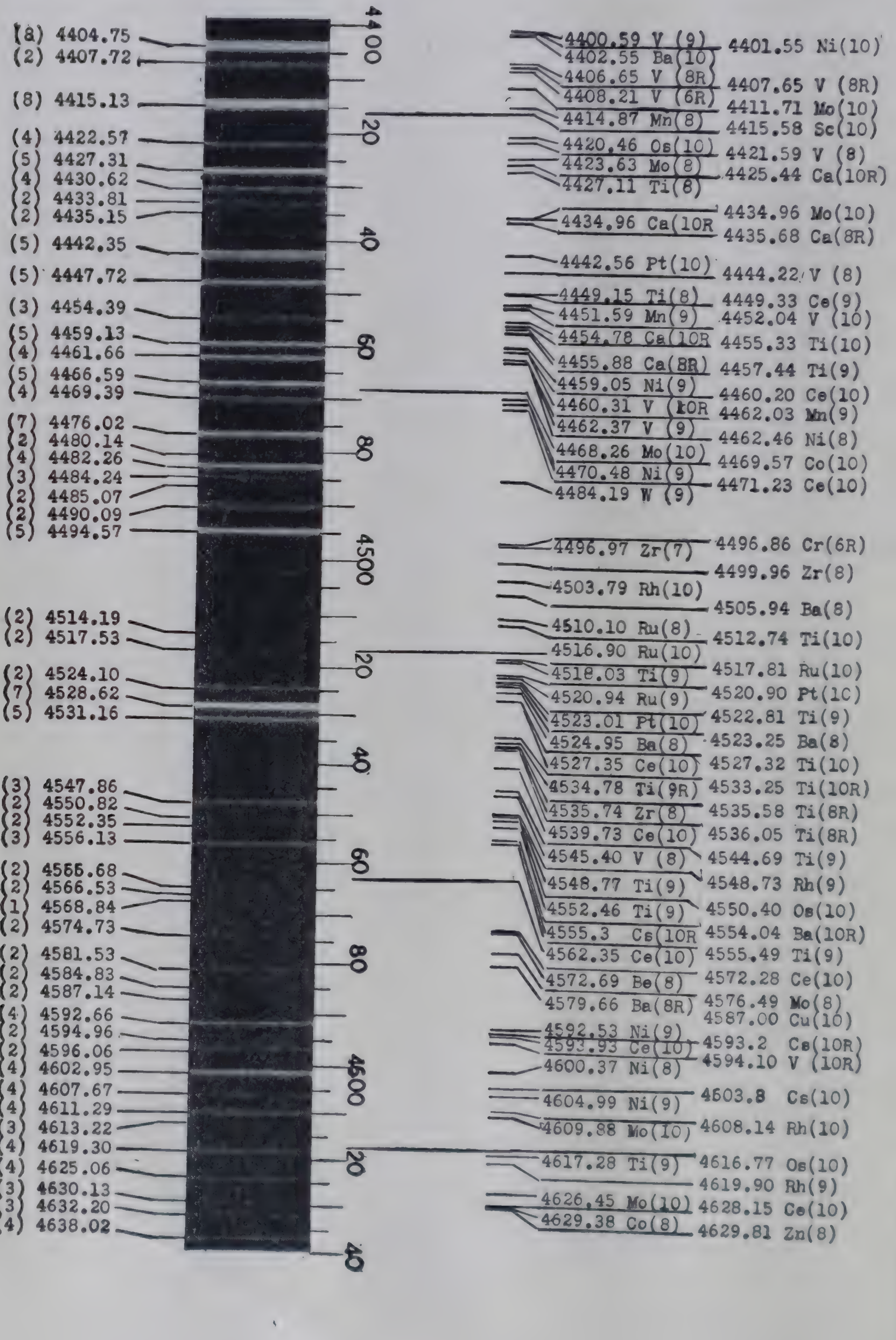


PLATE XXXV

4600–4840 A

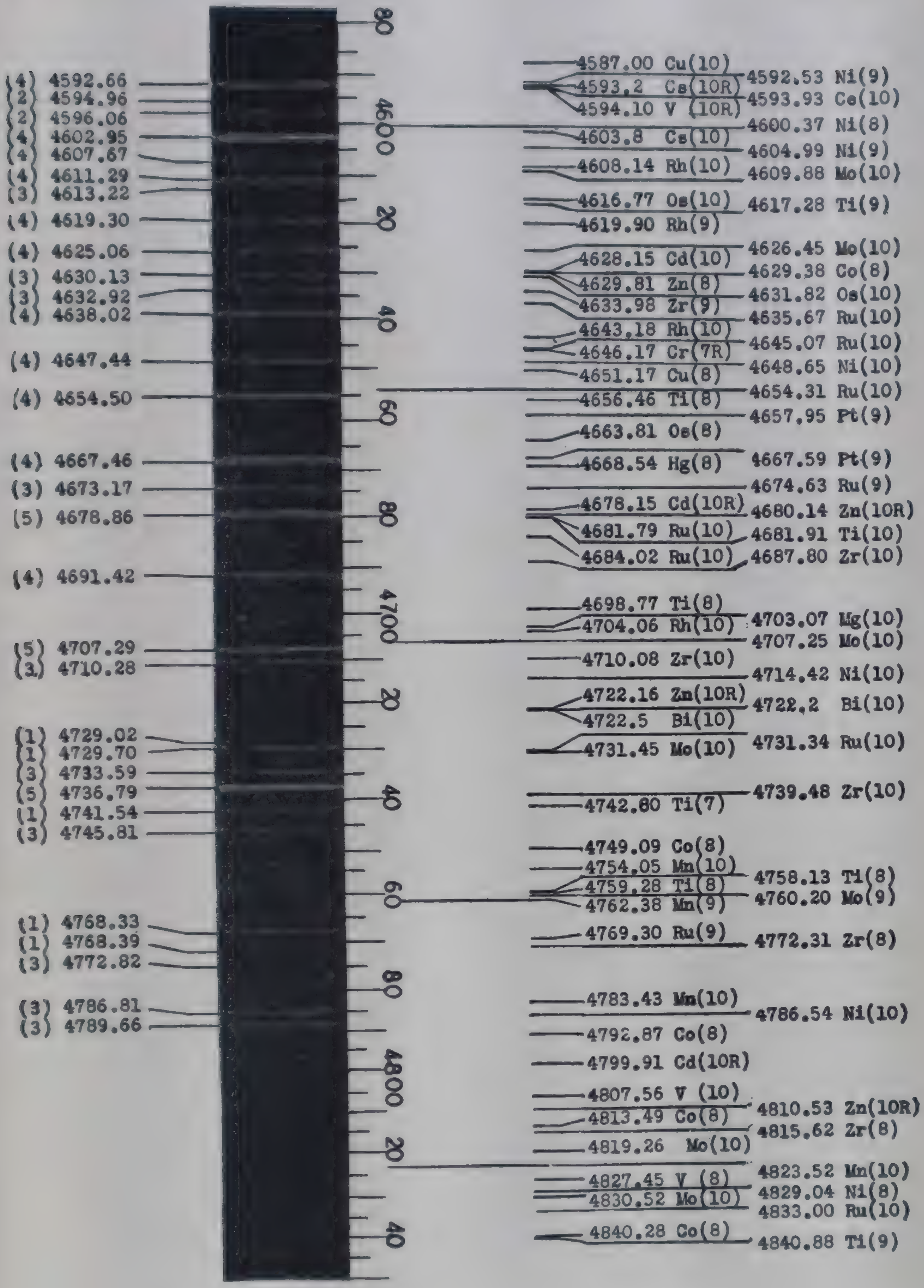


PLATE XXXVI

4800–5090

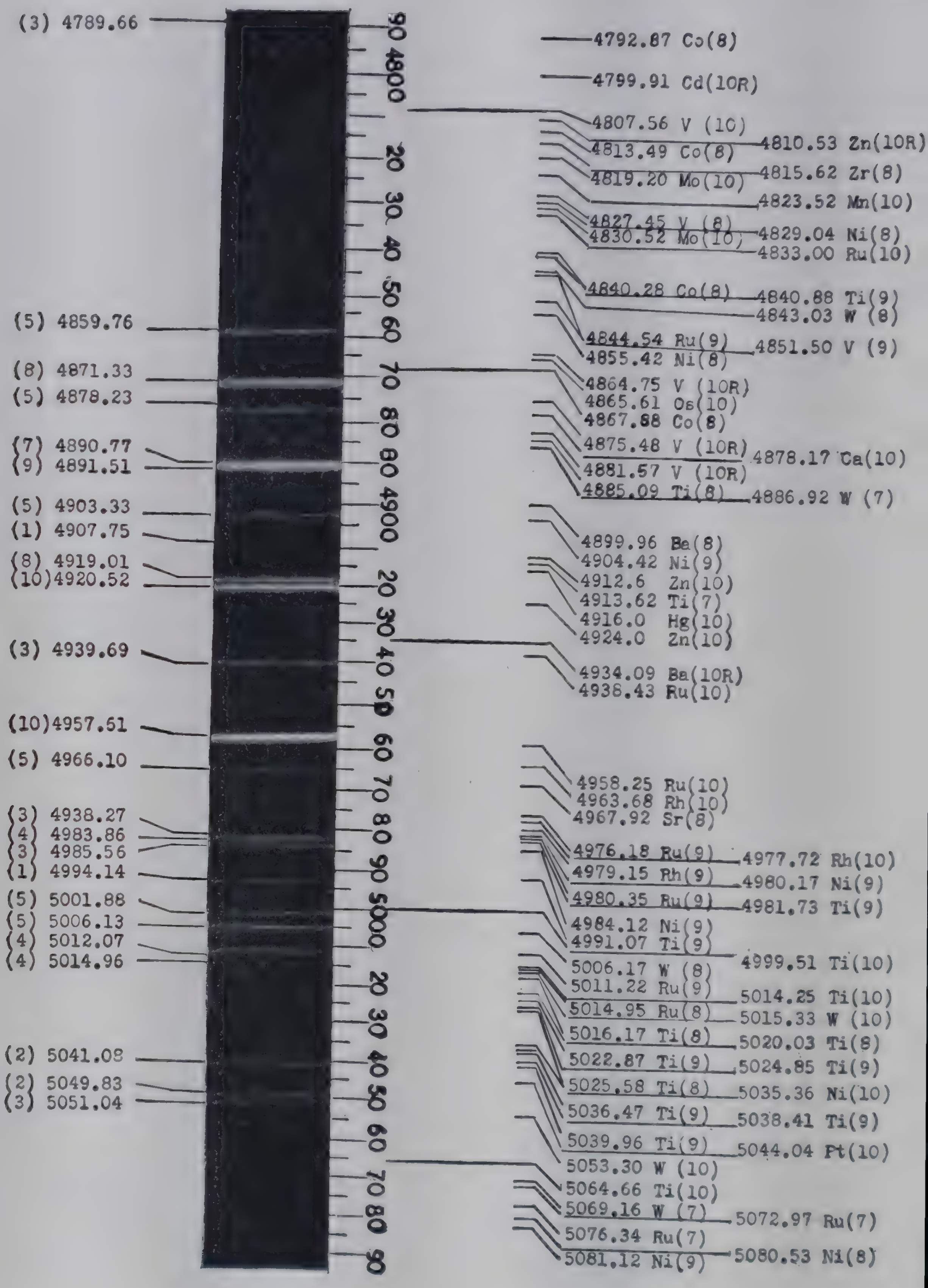


PLATE XXXVII

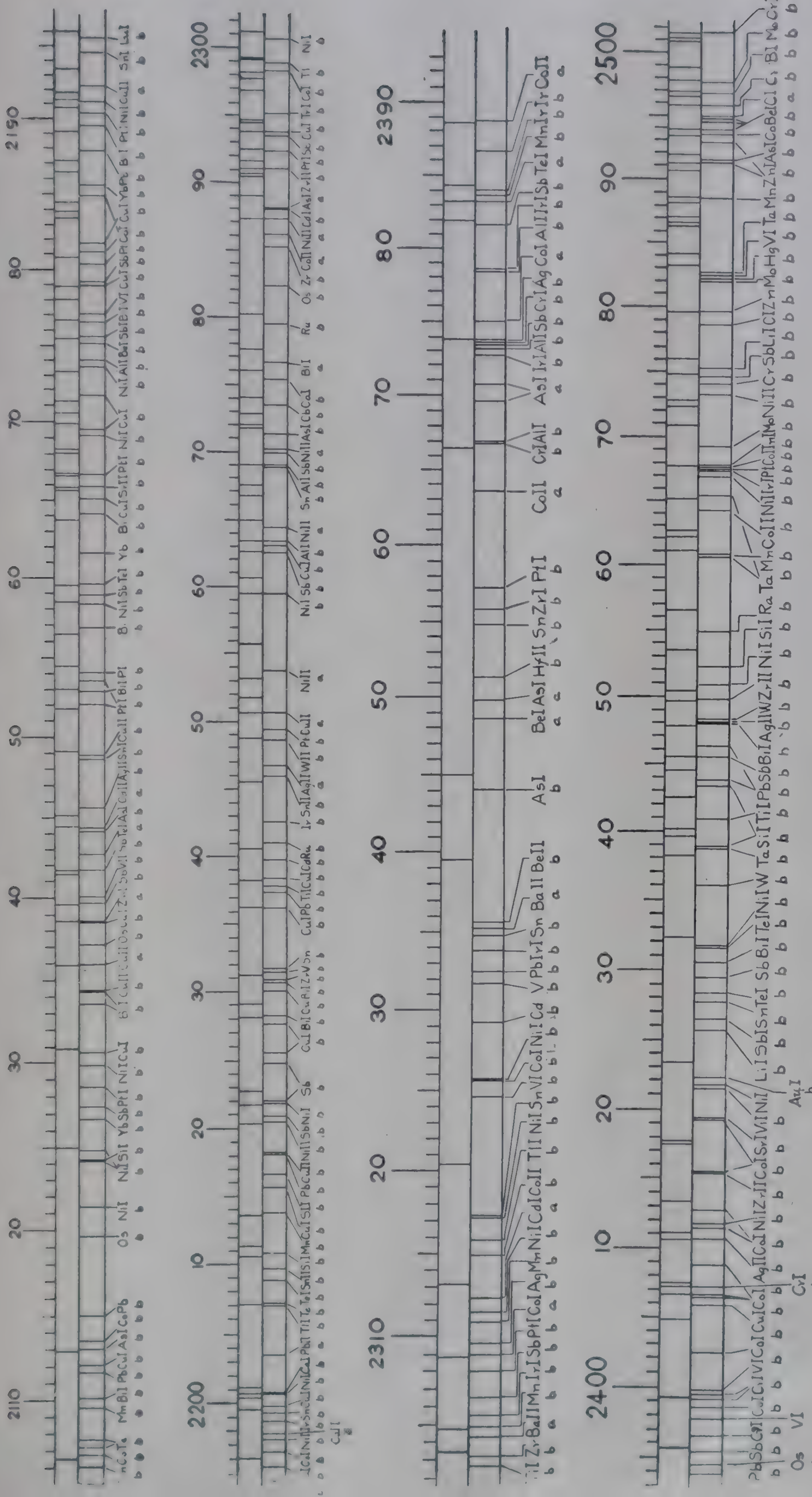


PLATE XXXVII. QUALITATIVE ANALYSIS CHARTS (Pierce (*C162*)).

Lines adjacent to scale indicate position of strong iron spectrum lines; lines in lower strip indicate the position of strong elemental spectrum lines as indicated by the symbols below the lines. (See also Tables IV*A* and IV*B*.)

PLATE XXXVIII

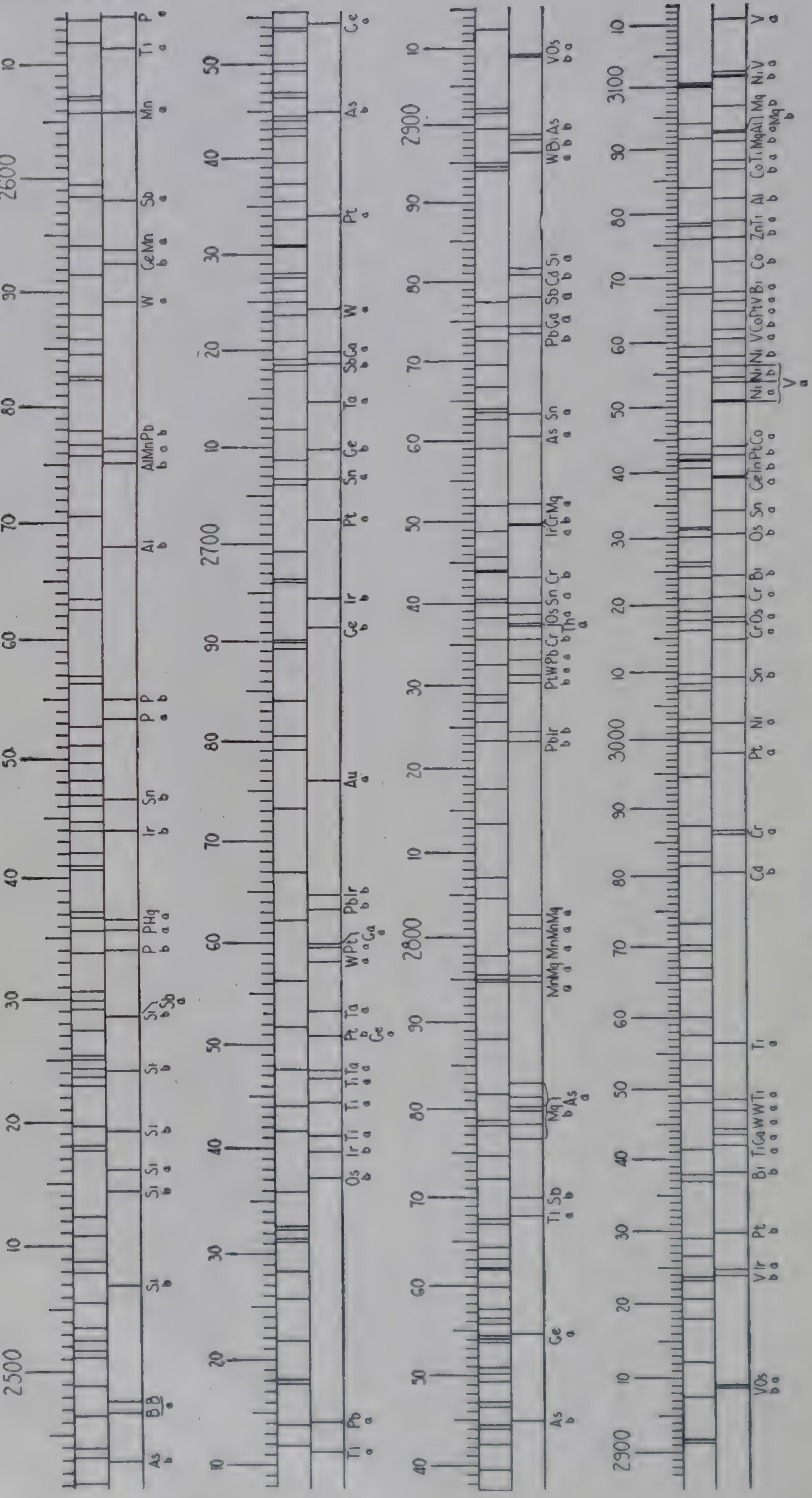


PLATE XXXVIII. Qualitative Analysis Chart.

PLATE XXXIX

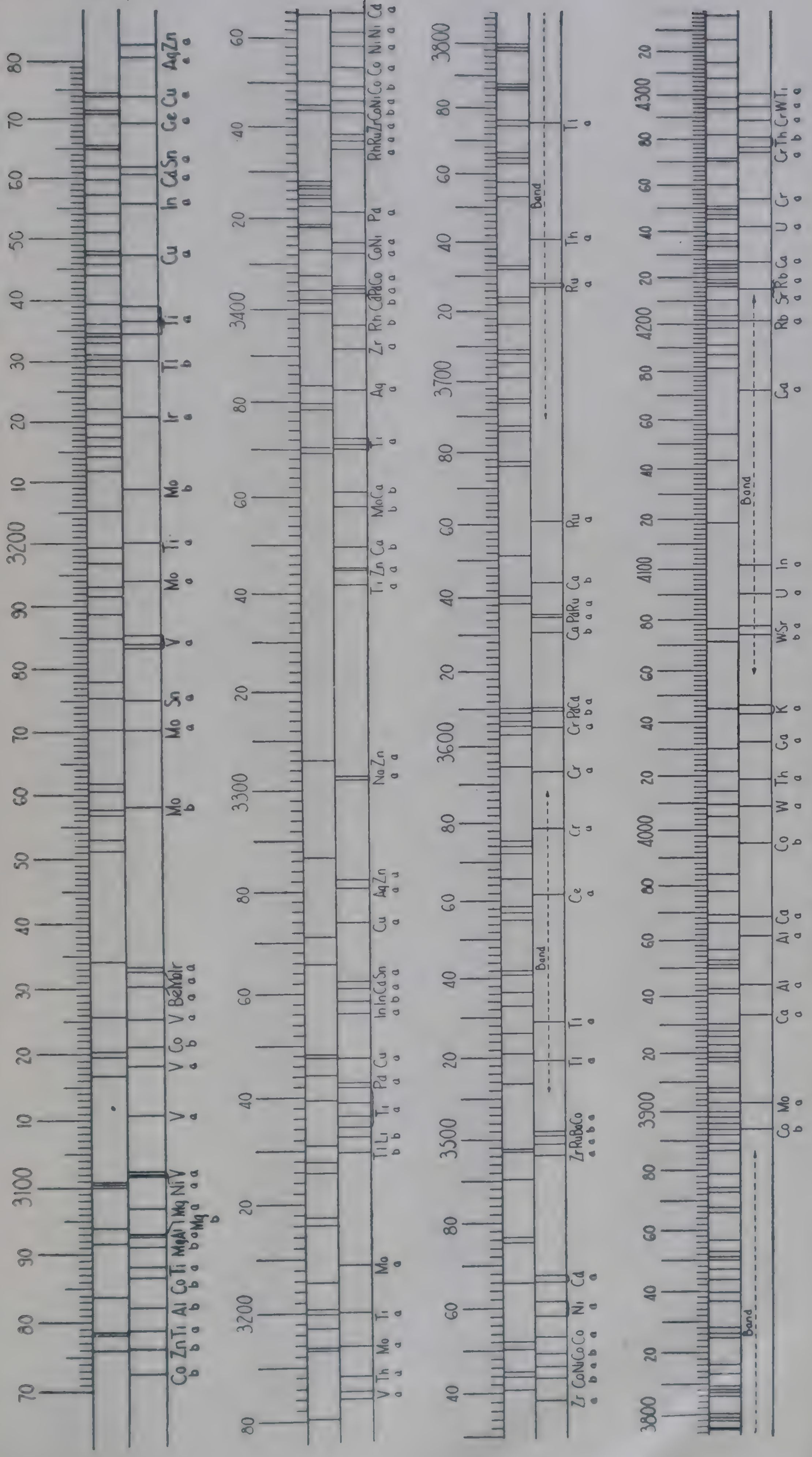


PLATE XXXIX. Qualitative Analysis Chart.

PLATE XL

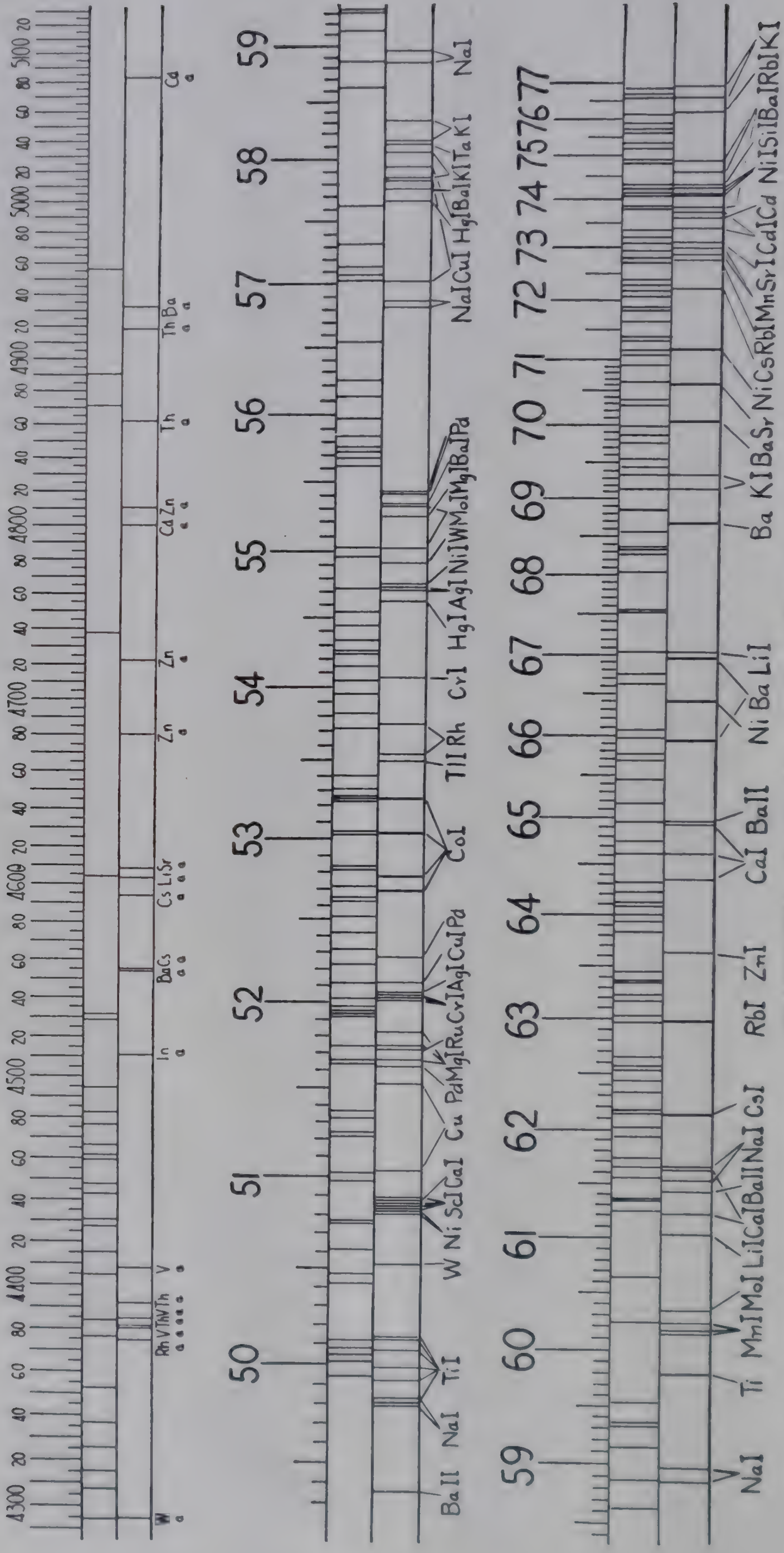


PLATE XL. Qualitative Analysis Chart.

PLATE XLI

Periodic Chart of the Atoms

	0	I	II	III	IV	V	VI	VII	VIII		
		R_2O	RO	R_2O_3	RO_2RH_4	$R_2O_5RH_3$	RO_3RH_2	R_2O_7RH	RO_4		
1		1 H 1.0078									
2	2 He 4.002	3 Li 6.940	4 Be 9.02	5 B 10.82	6 C 12.01	7 N 14.008	8 O 16.000	9 F 19.00			
3	10 Ne 20.183	11 Na 22.997	12 Mg 24.32	13 Al 26.97	14 Si 28.06	15 P 31.02	16 S 32.06	17 Cl 35.45			
4	18 A 39.944	19 K 39.096	20 Ca 40.08	21 Sc 45.10	22 Ti 47.90	23 V 50.95	24 Cr 52.01	25 Mn 54.93	26 Fe 55.8	27 Co 58.94	28 Ni 58.69
		29 Cu 63.57	30 Zn 65.38	31 Ga 69.72	32 Ge 72.60	33 As 74.91	34 Se 78.96	35 Br 79.916			
5	36 Kr 83.7	37 Rb 85.48	38 Sr 87.63	39 Yt 88.92	40 Zr 91.22	41 Cb 92.91	42 Mo 96.0	43 Ma	44 Ru 101.7	45 Rh 102.91	46 Pd 106.7
		47 Ag 107.880	48 Cd 112.41	49 In 114.76	50 Sn 118.70	51 Sb 121.76	52 Te 127.61	53 I 126.92			
6	54 Xe 131.3	55 Cs 132.91	56 Ba 137.36	57–71 Rare Earths	72 Hf 178.6	73 Ta 180.88	74 W 184.0	75 Re 186.31	76 Os 191.5	77 Ir 193.1	78 Pt 195.23
		79 Au 197.2	80 Hg 200.61	81 Tl 204.39	82 Pb 207.21	83 Bi 209.00	84 Po 210.0	85			
7	86 Rn 222.	87	88 Ra 226.05	89 Ac	90 Th 232.12	91 Pa 231.	92 U 238.07				

57–71 Rare Earths	57 La 138.92	58 Ce 140.13	59 Pr 140.92	60 Nd 144.27	61 Il	62 Sm 150.43	63 Eu 152.0
64 Gd 156.9	65 Tb 159.2	66 Dy 162.46	67 Ho 163.5	68 Er 167.64	69 Tm 169.4	70 Yb 173.04	71 Lu 175.0

INDEX OF SYMBOLS

(Definitions of common symbols are given on the indicated pages.)

A (angstrom), 4, 195, 196
A (absorption), 4
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B (Balmer), 196
(B) (absorption spectra literature reference), 6, 388
c (concentration), 4, 151
c (speed of light), 3, 4
(C) (research publications), 6, 391
cm^{-1} (unit of wavenumber), 4, 195
c.r.u. (constant resolution units), 197
d (electron configuration), 16
d (thickness), 4, 151, 189
d (optical density), 108
$d/\log I$ (plate calibration curve), 110
D (series term), 11
(D) (abstract publications and general articles), 6, 397
E (energy), 7
E (extinction), 4, 151, 190
E (extinction coefficient), 190
f (fresnel), 4, 195
f (electron configuration), 16
F (series term), 11
h (Planck constant), 7
I (transmitted light intensity), 4, 109, 151, 188, 189
$I_\circ$ (incident light intensity), 4, 109 188, 189
$I/I_\circ$ (transmission), 4, 188, 189
J (angular momentum), 15
k (specific extinction), 4, 151, 190
K (electron shell), 16
l (orbital quantum number), 16
L (electron shell), 16
L (orbital angular momentum), 15
m (integral series values), 11
M (electron shell), 16
mμ (unit of wavelength), 4, 195
N (negative spectrogram), 6, 373
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γ (photographic gamma), 118, 359
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(NOTE: No separate author index has been included. For author references the bibliography, arranged alphabetically by authors, should be consulted: A. Theory of Spectra, Qualitative and Quantitative Emission Analysis (books) pp. 83–388; B. Absorption Spectra and Colorimetry (books) pp. 388–391; C. Research Publications, pp. 391–396; and D. Abstract Publications and General Articles, p. 397. An index of symbols is given on pp. 661–662.)

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